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TECHNOLOGY UTILIZATION

CONTAMINATION CONTROL HANDBOOK

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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CONTAMINATION CONTROL HANDBOOK

Prepared by Sandia Laboratories
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for Marshall Space Flight Center

Technology Utilization Division
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FOREWORD

Rigid control of contamination has contributed to the reliability and precision of vehicles and instruments sent out to explore space. Experience gained in the aerospace community also can be helpful in the pharmaceutical, electronic, and many other industries in which extreme cleanliness is important. This is one of three Special Publications issued by the NASA Office of Technology Utilization to help extend and diffuse current concepts and techniques of rigorous contamination control.

The first of these documents, Contamination Control Principles, SP-5045, was issued in 1967 when a NASA Contamination Control Panel called attention to the widespread need for guideline information. The George C. Marshall Space Flight Center, the Manned Spacecraft Center, and the John F. Kennedy Space Center were represented on that panel by, respectively, Frederick J. Beyerle, Quintin T. Ussery, and Dr. John Gayle. Since then a number of special courses for technicians and supervisors employed in clean rooms have been given, and the lectures prepared by James W. Useller for one of those courses at the Lewis Research Center have been published in Clean Room Technology, SP-5074.

This handbook deals in more detail with many of the same matters discussed in SP-5045 and SP-5074. It was prepared for the George C. Marshall Space Flight Center under the direction of H. D. Sivinski, Manager of the Planetary Quarantine Department at the Sandia Laboratories and one of the authors of Contamination Control Principles. He was assisted in this work by a team that included D. M. Garst, K. F. Lindell, W. J. Whitfield, and J. A. Paulhamus and their associates at the Sandia Laboratories; Dr. John Beakley and L. Hughes of the University of New Mexico, and Mrs. Dorothee Drury, technical editor.

The authors' purpose was to assemble in one volume the information and data most likely to be of practical help to persons engaged in contamination control in industrial and related operations. Although commercial names have been used, mention of them does not constitute endorsement by the authors or any Government agency. The group responsible for this work drew on many sources of information and has included matters about which there may still be controversy, but the information presented has been verified to the extent believed practical.

Ronald J. Philips, Director
Technology Utilization Division
Office of Technology Utilization

CONTAMINATION CONTROL HANDBOOK

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SECTION 1

INTRODUCTION TO CONTAMINATION CONTROL

To effectively control contamination, a multipoint program is required from the design stage through to final application. A broad range of knowledge must be brought to bear on the problem ranging from types of cleaning agents to contamination monitoring techniques, from material composition to kinds of soils. Because of the breadth of the problem and the wide range of disciplines encountered, it is necessary for anyone with the responsibility for initiating and administering a contamination control program to understand:

a. What constitutes contamination

b. The environments in which contaminants are found

c. The effects of contamination

d. The means by which contamination may be controlled and monitored.

These factors and their relationship are graphically portrayed in Figure 1-1.

In order to establish a frame of reference, it might be good at this point to define a few basic terms which are used throughout this handbook. These and other terms may be found in the Glossary (Section 11).

Contaminant	- Any material, substance, or energy that is unwanted or adversely affects the contaminee.
Contaminee	- That which is or can be contaminated. Contaminees may be products, materials, devices, people, gases, or surfaces.
Environment	- The total of all factors which might influence or cause contamination of a contaminee. The primary factors of environment are the forms air, gas, liquid, solid, or surfaces.
Contamination Control	- The planning, organization, and implementation of all activities needed to determine, achieve, and maintain a required cleanliness level in, on, or around the contaminee.

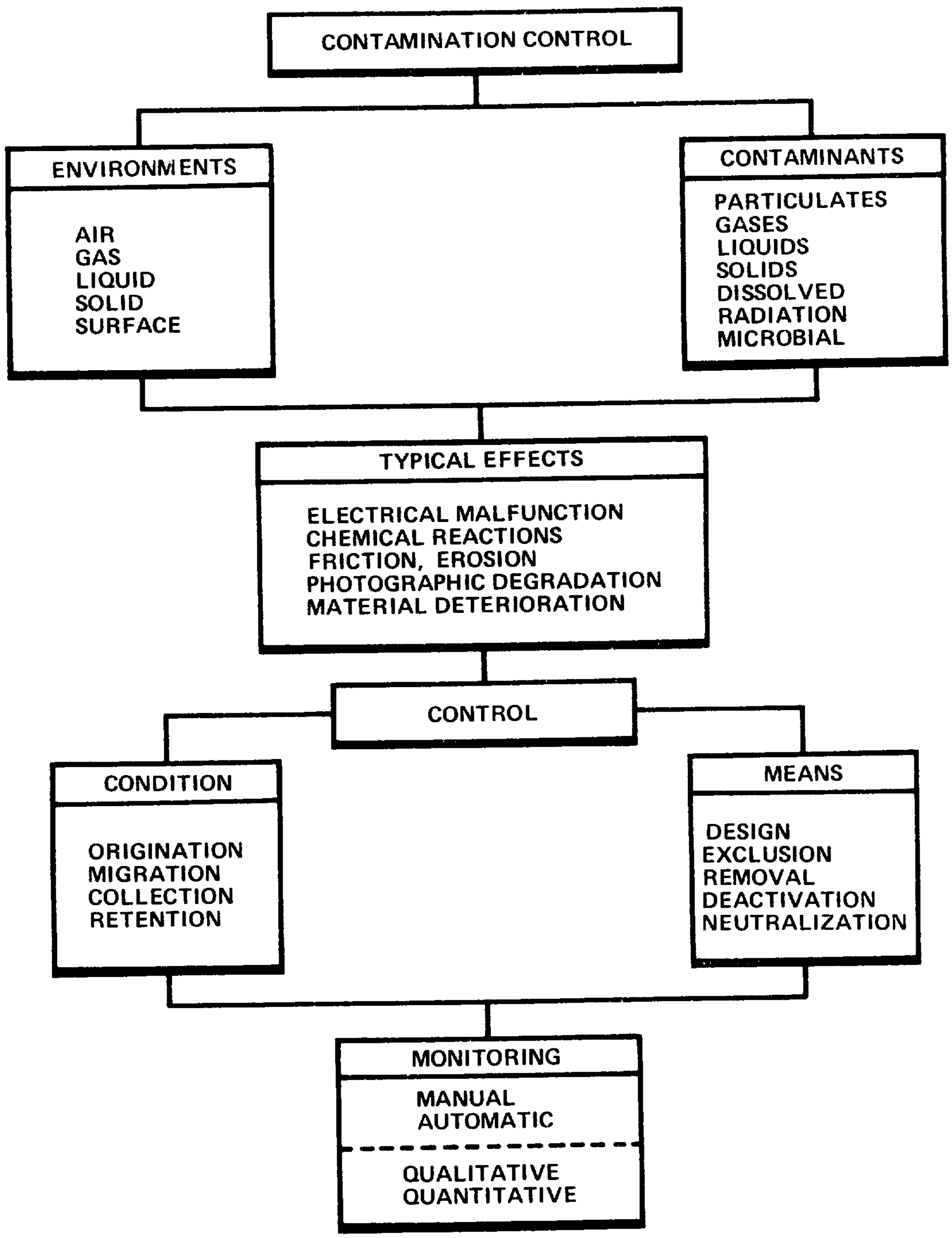


Figure 1-1. The primary elements of contamination control and their relationship

Cleanliness is not absolute; it is a relative condition denoting the degree to which a contaminee can be isolated from or cleansed of contaminants. A level of required cleanliness must first be established for a contaminee before it can be determined what techniques are needed to achieve the desired result. A multipoint contamination control program can then be designed by taking the following steps:

a. Determine the degree of cleanliness required in order to permit the contaminee to function satisfactorily.

b. Prepare a design with optimum materials, configuration, and tolerances to help attain the desired cleanliness level.

c. Select and train personnel in contamination control techniques. Plan refresher courses before the contamination control operations begin.

d. Select and obtain the proper materials, equipment, and methods best suited to do the assigned job.

e. Process the product flow so as to minimize the chance for recontamination after cleaning operations.

f. Select personnel and equipment to perform the monitoring task.

1.1 Contaminants

A contaminant is defined as "Any material, substance or energy that is unwanted or adversely affects the contaminee." This definition is intentionally broad so as to emphasize the scope of the subject and to adequately encompass its many ramifications. Some of the ways in which contaminants may be grouped are:

a. Sources

b. Viability

c. Environment in which normally found

d. Form or state (particle, gas, liquid, wave, etc.)

e. Chemical composition

f. Removal reaction to cleaning agents and methods

g. Effects on materials and function.

Each of the groups above could be expanded almost infinitely to add depth and detail to their description as was done for source and form in Table 1-1.

It should be emphasized that any given material or energy may be a contaminant in one situation yet may be desirable or not be considered a contaminant in a different situation. This location or environment-dependent relationship is clearly shown in the following examples:

TABLE 1-1

Contaminant Sources and Forms

SOURCES AND RELATED CONTAMINANTS	CONTAMINANT FORM OR STATE					
	Particulate	Gaseous	Liquid	Film	Radiation	Microbial
ATMOSPHERE:						
Condensates			X	X		
Airborne particulate	X					X
Gas		X				
CLOTHING:						
Lint and fibers	X					
INDUSTRIAL PROCESSES:						
Chemical films				X		
Chemical vapors		X		X		
Chips and burrs	X					
Combustion gases		X				
Cleaning solvents			X			
Coolants and oils			X			
Flue dust	X					
Flux particles	X					
Flux vapors		X		X		
Lubricants			X	X		
Machining: heat, sound, vibration					X	
Oxides				X		
Plating baths			X	X		
Sand, etc.	X					
Smoke fumes	X	X				
Solder/weld spatter	X					
Soldering, heat					X	
Solvent residue				X		
Sublimated flux		X				
Welding: light, heat					X	
PEOPLE:						
Bacteria and virus	X					X
Body vapors		X				
Cosmetics	X					
Epidermal scale	X					X
Hair	X					
Skin oils			X			X
Rickettsiae	X					X
Tobacco smoke	X					
PLANTS:						
Fungi	X					X
Pollen	X					X
PRODUCT:						
Corrosion	X	X				
Material shedding	X					
Outgassing		X		X		
Sublimated materials from flux, plastics, etc.		X		X		
Wear particles	X					
RADIOACTIVE MATERIALS:						
Alpha particles	X				X	
Beta particles	X				X	
Electrons	X				X	
Gamma rays					X	
Neutrons	X				X	
SOIL:						
Bacteria	X					X
Fungi	X					X
Protoza	X					X
SUN:						
Electromagnetic					X	
Ultraviolet					X	
Visible light					X	
X-ray					X	
TRANSPORTATION:						
Exhaust fumes	X	X				
Wear particles: tires, wheels, paint, etc.	X					
Wear particles: road, rails	X					
CONSTRUCTION:						
Dust	X					
Fumes	X	X				
Sawdust	X					

a. The products of oxidation are normally contaminants, yet controlled oxidation protects aluminum and provides other useful materials.

b. Light is an essential medium, but it is a contaminant in a photographic dark room.

c. Microbial organisms provide many useful services, yet under different circumstances are the cause of disease to man and animals.

d. Lubrication products are needed for many moving parts but must be completely absent in many other devices, such as electrical contacts.

The enormity and complexity of the field of contamination control can only be suggested by the foregoing discussion.

1.2 Environments

Contaminants can be in, on, or around the contaminee or the environment in which the contaminee is located. In nearly all instances, however, the environment is the contaminating influence, and the sequence of contamination is as follows:

SOURCE ⟶ ENVIRONMENT ⟶ CONTAMINEE

In contamination control, a distinction should be made between:

a. <u>Critical Environment</u> -- Those factors, conditions, or influences in the immediate vicinity of or in contact with the contaminee.

b. <u>General Environment</u> -- Those factors, conditions, or influences in the same general area (rooms, bench, enclosure, work station) in which the contaminee is located.

The general types of environment are air, gas, liquid, solid, and surface. Specific factors which are frequent offenders in contributing contamination are people, tools, fixtures, equipment, control devices, etc.

Because a complex and critical relationship exists among contaminants, environments, and the contaminee, much contamination control effort is directed toward removing contaminants from environments before they come in contact with the contaminee. This preventive rather than corrective approach is desirable in most cases and essential in some.

1.3 The Origin of Contamination - Sources and Types

Contamination is the product of activity. Activity is the result of expended energy and may be mechanical, chemical, electrical, thermal, or radiological in nature. Virtually every activity of man generates or contributes to the generation of contamination.

Likewise, naturally occurring activity further contributes and distributes contamination. Theoretically, a perfectly clean environment can be attained only in a complete vacuum, devoid of all life and activity. As the amount of man-made activity increases, the amount of contamination to be contended with also increases. It is imperative, therefore, that means be found to eliminate or control contamination to a tolerable level.

In order to develop controls for contamination, it is first necessary to recognize the sources and the types or forms of contamination produced. Table 1-1 should serve as a guide to this recognition; it is not intended as an all-inclusive list of contaminants.

1.4 The Mechanisms of Contamination Migration

If all contaminants were immobile, many contamination control problems would never exist. However, activity not only creates but also provides the mechanisms for moving contaminants from one place to another. Contaminant migration generally takes place as described in Table 1-2.

TABLE 1-2

Contaminant Migration Mechanisms

Carrier	Method of Movement
Fluids	Contaminants are suspended, adsorbed, or dissolved in the fluid. Particulates are dropped out as velocity decreases or as they become attached to surfaces.
Solids	Entrapped, adsorbed, or absorbed contaminants are moved as the solid is moved from place to place.
Physical contact carriers	Migration occurs by means of the operators hands, tools, fixtures, etc.
Waves	In most cases, such as with heat, light, sound, etc., the propagation mechanism is an inherent characteristic of the contaminating energy.

1.5 The Mechanisms of Contamination Retention

Contamination retention usually occurs through the attachment of particles, liquids, and gases to surfaces. The type and strength of the forces exerted to hold the contamination to a surface are important considerations in determining the most appropriate method of removal.

The more common mechanisms of retention are listed below:

a. Gravity -- The amount of contamination retained by gravitational forces depends on the angle of the surface from horizontal.

b. Electrostatic Charges -- Such charges not only hold contamination, but also attract it from the surrounding environment. If possible, the polar characteristic of a cleaning agent should match that of the soil to be removed.

c. Molecular Attraction -- Involves adhesion and adsorption and the effects of van der Waal's forces. It is directly affected by particle size, shape, composition, and contact area as well as the surface roughness.

d. Viscous Surface Coatings -- A common cause of contamination retention particularly where machining, lubricating, or skin oils are encountered.

e. Physical Entrapment -- Should be a definite consideration for rough surface finishes or porous surfaces and materials.

1.6 Bibliography

"The Adhesion of Solid Particles to Solid Surfaces, A Review:" Morton Corn; presented at the 54th Annual Meeting of the Air Pollution Control Association, New York, New York; June 11-15, 1961.

Contamination Analysis and Control: James L. Dwyer; Reinhold Publishing Corporation, New York, New York; 1966.

Contamination Control Principles: NASA SP-5045; 1967.

SECTION 2

CONTAMINATION CONTROL IN PRODUCT DESIGN

The objective of considering contamination control at the product design stage is to eliminate contamination that might constitute a hazard or interfere with the intended function of the product. All too often, contamination control procedures are not developed until after a product failure has taken place. It is difficult to foresee every potential contaminant in every case; but many costly rejects caused by contamination might have been prevented if contamination control had been a factor in product design. At this stage, features can be incorporated in the design to:

a. Minimize or eliminate sources of contaminant generation

b. Render the product least susceptible to contamination

c. Facilitate contamination removal and monitoring.

2.1 Control of Contaminants Through Product Design

To create a truly effective design, the product designer must be aware of more than just the function and reliability requirements; he must also be aware of the following factors of the total product life:

a. Cleanliness requirements

b. Manufacturing and processing environments

c. Manufacturing processes

d. Test procedures and equipment

e. Storage and use conditions.

In taking specific steps to control contamination, the designer should

a. Consider all possible sources, types, and amounts of contamination which the product may encounter

b. Be aware of the different control techniques available

c. Specify requirements and features which will help achieve and maintain the needed cleanliness level.

Table 2-1 gives more detail on these three areas. The items listed under each heading in this table may be considered in any logical sequence and not necessarily in the order listed.

The following checklist is designed to assist in determining whether all reasonable contamination control measures have been considered. It may be necessary to modify this checklist for special situations or products considered, but it should give an idea of the approach to be taken.

Designer's Contamination Control Checklist	
1.	Identify contaminant-sensitive parts, assemblies, surfaces, ports, areas, etc., that require some level of cleanliness.
2.	Define the level of cleanliness required.
3.	Define the contaminants that cannot be tolerated.
4.	Define purity requirements for basic materials.
5.	Define sequences of assembly to facilitate controls.
6.	Define cleaning methods to be employed.
7.	Define cleanliness levels required for assembly and process areas and facilities.
8.	Define purity requirements of materials used in production and cleaning processes.
9.	Define methods for measuring cleanliness levels of controlled areas and facilities.
10.	Define methods to be employed for excluding contaminants from clean items and assemblies.
11.	Define tests and measurements to verify effectiveness of control techniques.
12.	Define methods for servicing or maintenance operations that assures continuity of the required cleanliness level.

Table 2-2 provides a detailed list of factors which may affect contamination of the product. This list should be used in conjunction with the checklist above.

TABLE 2-1

Contamination Control Considerations for Designers

Considerations	Techniques for Control	Specific Methods
How clean does the contaminee have to be?	Eliminate the contaminant and its source.	Material -- Select compatible, noncorrosive, low contaminant-generating materials.
How much and what kind of contamination can be tolerated?	Exclude the contaminant from the contaminee.	Configuration -- Design to facilitate cleaning, flushing, and monitoring; eliminate blind holes and dirt traps, isolate sensitive areas.
What are the contaminants?	Reduce the size and volume of the contaminant in the critical environment.	Dimensions -- Specify maximum tolerances allowable and suitable surface finishes.
Where do the contaminants come from?	Minimize the affect of the contaminant.	Processes -- Specify manufacturing and cleaning processes and process controls to be compatible with cleanliness levels required.
How do the contaminants travel to the contaminee?	Remove contaminant generating materials.	Monitoring -- Specify best available monitoring techniques for each type of contaminant encountered.
How do the contaminants effect the contaminee?		Storage and Use -- Specify the type and method of packaging needed to protect the product, i.e., moisture-proof, nonshedding, sealable, strong, etc. Maintenance instructions may be included.
How can the contaminants best be removed?		
What cleaning methods are suitable? Satisfactory?		
What cleaning solutions are not compatible with materials?		

TABLE 2-2

Factors Affecting Contamination in Product

General Areas of Consideration		Characteristics for Design Considerations
Materials	Purity	Electrical Mechanical Method of analysis
	Generation of contaminants	Corrosion Outgassing Wear products Shedding Flaking
	Workability	Burrs Flashing Galling Finish
	Compatibility with other materials	Corrosion Galvanic action Galling Wear Lubricants Preservatives Reaction to cleaning
Configuration	Parts	Accessibility to surfaces Blind holes Capillary traps
	Assemblies	Accessibility to sensitive areas Mating of materials Generation of contaminants Protection of parts
Dimensioning	Parts	Tolerance limits Contaminant limits
	Assemblies	Mating surfaces Contaminant limits
Fabrication (forming and finishing)	Casting	Sand and cores Residues Blind holes Capillary traps Entrapped gases

e. General Aspects of Degreasing Solvents:

Trichloroethylene

(1) most widely used

(2) optimum from efficiency and cost

(3) stabilization easily controlled

(4) temperature of cleaned parts acceptable

(5) high solvency power

(6) easily and effectively distilled

(7) lower heating needs than perchloroethylene.

Perchloroethylene

(1) removes moisture and moisture content of aqueous solutions

(2) stabilized solvent shows little tendency to hydrolyze

(3) higher boiling point advantages:

(a) better removal of tars and waxes with melting points in the 190° to 250°F range

(b) reduced staining of light-gage metal

(c) parts undergo longer cleaning cycles

(d) more complete drying of work.

(4) higher boiling point disadvantages:

(a) heating requirements higher and more costly

(b) may bake insoluble contaminants on parts

(c) higher solvent vapor temperature may not be compatible with certain materials.

Methylene Chloride

(1) lowest boiling point of usual degreaser solvents

(2) reduced degreaser heat requirements

TABLE 3-16

Properties of Vapor Degreasing Solvents[a]

Solvent	Boiling Point (°F)	Surface Tension at 68°F (dynes/cm)	Latent Heat at Boiling Point (Btu/lb)	Toxicity Threshold Limit (in PPM)[b]	Specific Gravity of Vapor (air = 1.00)	Kauri-Butanol Value
Trichloroethylene	188	$32.0^{77°F}$	103	100	4.54	130
Perchloroethylene	250	32.3	90	100	5.73	90
Trichlorotrifluoroethane	117.6	19.6	63.1	1000	6.75	31
Methylene chloride	104	28.2	142	500	2.93	136
Methyl/chloroform	165	$25.5^{74°F}$	95	350	4.50	130

(a) A complete list of solvents and their properties is included in Paragraph 3.5.2.
(b) Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.

(1) the work piece is lowered into the vapor zone of the degreaser

(2) the solvent vapor condenses on the cooler parts, dissolving the contamination

(3) the condensed vapor flows down over the part, carrying the contamination to the boiling liquid in the bottom of the tank

(4) condensation ceases when the part reaches vapor temperature

(5) the part is raised out of the degreaser and it immediately dries.

c. Types of Cleaning Agents Used -- Selection of the proper degreasing cleaning agent requires a study of the particular application including such factors as the material to be cleaned, the type and amount of contaminant to be removed, the configuration of the material, and the cost and reclamation potential of the cleaning agent. The solvents commonly used for vapor degreasing are:

trichloroethylene
perchloroethylene
trichlorotrifluoroethane
methylene chloride
methyl chloroform
azeotropic mixtures

Properties of vapor degreasing solvents are shown in Table 3-16.

d. Degreaser Solvent Criteria -- Solvents used for vapor degreasing should meet all or most of the following criteria:

(1) high solvency for oils, greases, waxes, and similar contaminants

(2) high vapor density relative to air

(3) boiling point within a range to facilitate vapor condensation on the work and readily permit separation from contaminants by distillation

(4) relatively low heat of vaporization and specific heat

(5) noncorrosive to metals of construction or to the work piece; usually stabilized or inhibited

(6) chemical stability as used for degreasing

(7) nonexplosive, nonflammable, and controllable as to health hazards.

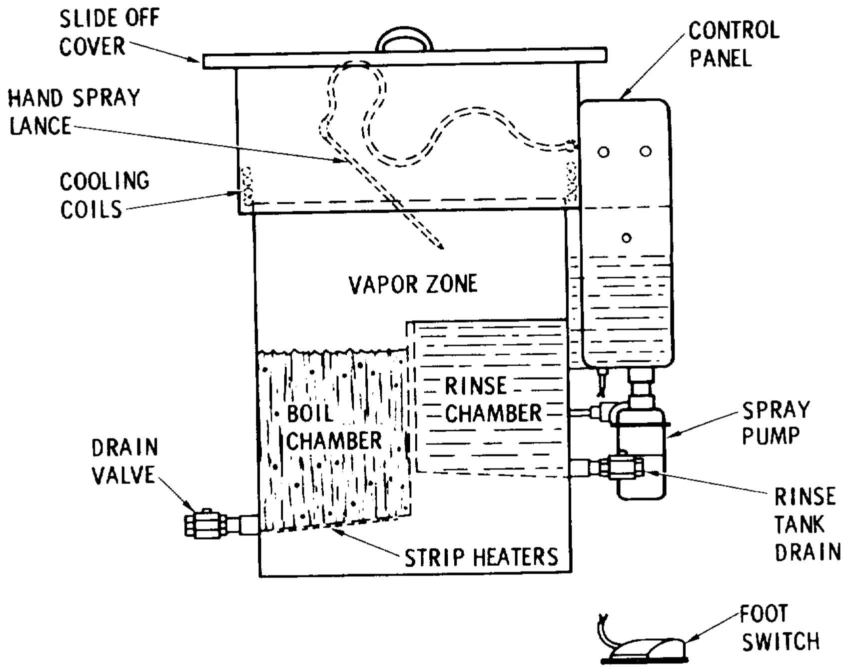
TABLE 3-15

Types of Vapor Degreasers

Type of Cycle	Application
1. Vapor only	Removal of light soils soluble in the degreasing solvent; flat surfaces or other simple shapes.
2. Spray-vapor	Used primarily for compounds which would be baked on the workpiece if first subjected to vapor degreasing.
3. Vapor-spray-vapor	More effective in removing medium light soils and insoluble contaminants, penetrating blind holes, and cleaning partially accessible complex shapes.
4. Vapor-immersion-vapor	Generally used for removing medium heavy soils on parts with thin wall sections or small bulk parts in baskets or other containers.
5. Boiling solvent-cool solvent-vapor	Effective for loosening and removing heavy soils and for cleaning closely basketed complex shapes.
6. Ultrasonic	Combined with vapor degreasing, produces a higher degree of cleanliness; applied after pre-cleaning; followed by spray and vapor rinses; may be used for small, intricate parts, printed circuit boards, castings, miniature assemblies, and removing contamination from blind holes or remote surfaces.
7. Other combinations	Other cycle combinations may be devised for special cleaning needs. Experienced equipment manufacturers can furnish this assistance.

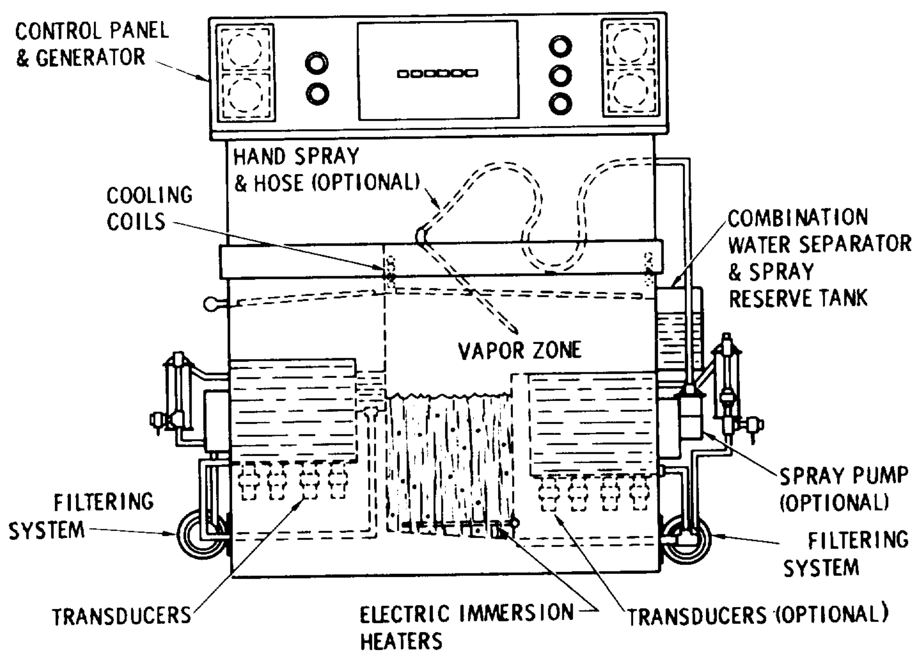
Vapor degreasing produces a degree of cleanliness sufficient for many industrial operations. When used with an ultrasonic unit, it provides cleanliness levels that are adequate for precision and miniaturized parts and for subsequent electrical or electrochemical processes. A degree of cleanliness between 1.0 and 0.1 monomolecular layers of contamination has been achieved.

b. Operation -- The steps normally followed in vapor degreasing parts are outlined below:



Courtesy of Baron-Blakeslee Inc.

Figure 3-6. Vapor-immersion-spray degreaser



Courtesy of Baron-Blakeslee Inc.

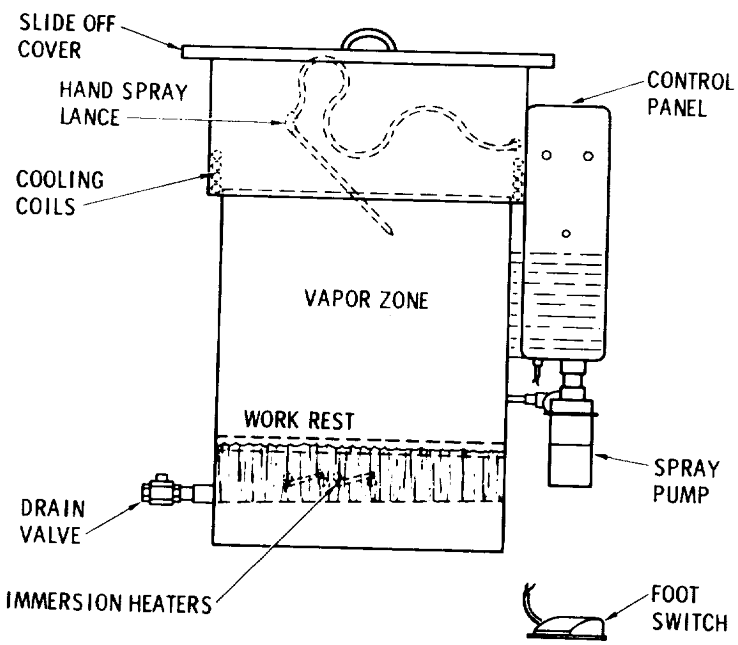
Figure 3-7. Ultrasonic vapor degreaser

Many deionizing systems are designed to reuse the deionized water after it has been used for washing or rinsing purposes. The impurities picked up are generally much less and more easily removed than the impurities in raw water.

Maintaining the sterility of high purity water is an operating consideration which requires periodic or constant surveillance and control in bacteria-sensitive systems. Flushing the system periodically with sodium hypochlorite or other liquid sterilizing agents will control bacterial growth in most instances. Bacterial growth can also be retarded if the water in the system is not exposed to air. If resins become coated with bacteria, their effectiveness may be seriously reduced or completely eliminated.

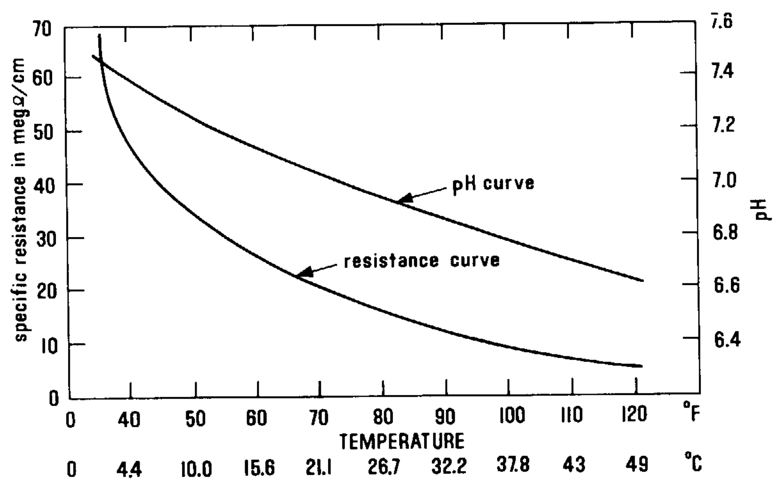
3.4.2 Vapor Degreasing

a. General -- Vapor degreasers use solvent vapors to chemically dissolve and use condensate to remove solvent soluble contamination such as oils, greases, and organic matter from part surfaces. Other types of contaminants held to the part by the solvent soluble contaminants are usually also removed by the cleaning action. Several types of vapor degreasers are shown in Figures 3-5, 3-6, and 3-7. Other variations available on degreasers are described in Table 3-15.



Courtesy of Baron-Blakeslee Inc.

Figure 3-5. Vapor spray degreaser



Curves illustrating the variation in theoretical resistivity and pH of pure water with varying temperatures.

Source: "Monitoring Water Quality with the Solu Bridge," A. W. Michalson, The Analyzer, February 1967.

Figure 3-4. Resistivity and pH of pure water with varying temperatures

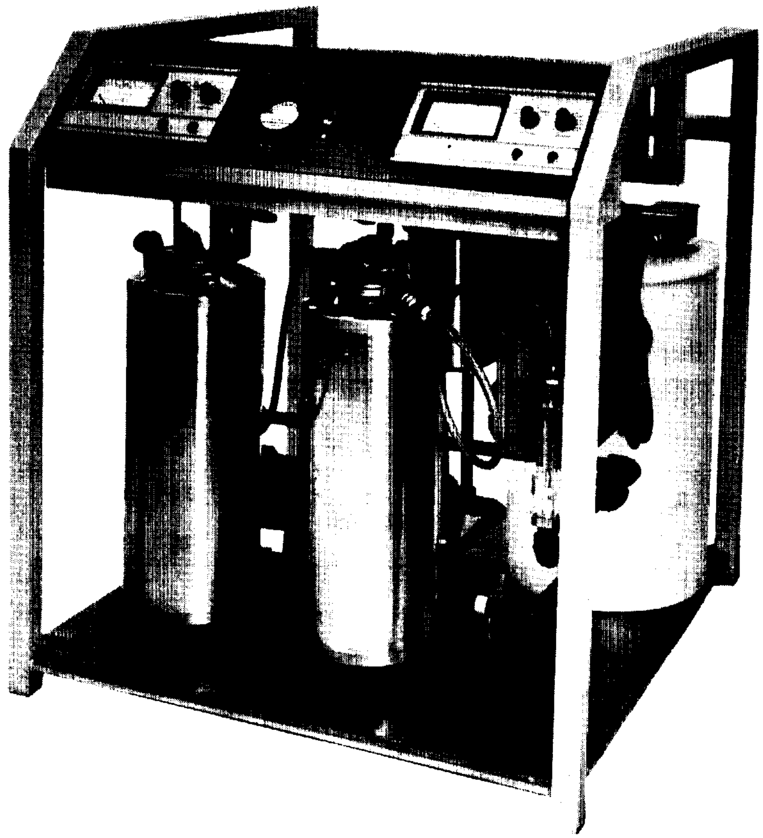
TABLE 3-14

Conductivity Versus Concentration in ppm for Water Analysis

Ion by Analysis	μmho/cm/ppm	ppm/μmho/cm
H	347.2	0.0029
Ca	2.99	0.334
Mg	4.41	0.227
Na	2.21	0.453
HCO_3	1.14	0.877
CO_2	2.30	0.435
OH	11.29	0.089
SO_4	1.69	0.610
Cl	2.13	0.470
PO_4	2.24	0.447
NO_3	1.14	0.877
Na_2CO_3	2.26	0.448
$NaHCO_3$	1.44	0.695
NaCl	2.16	0.463
Na_3PO_4	2.23	0.448
Na_2SO_4	1.87	0.535
NaOH	6.07	0.165
$CaSO_4$	2.03	0.493
$CaCO_3$	2.58	0.399
SO_3	2.22	0.45

The above values are for infinitely dilute solutions. As concentrations increase, the values for ppm per μmho increase because of decrease in ionization in the solution.

Source: "Monitoring Water Quality with the Solu Bridge," A. W. Michalson, The Analyzer, February 1967.



Courtesy of Interlab, Inc., Pleasantville, New York

Figure 3-3. Water purification system

TABLE 3-13

Tabulation of Dissolved Solids Measurements in ppm Versus Conductivity and Resistivity at 25°C for Deionized Water

ppm as NaOH	ppm as NaCl	Specific Resistance (ohms/cm)	Specific Conductance (μmho/cm)
0.000	0.000	18,000,000	0.055
0.000	0.002	17,000,000	0.060
0.001	0.004	16,000,000	0.063
0.005	0.01	12,000,000	0.085
0.009	0.03	9,000,000	0.11
0.016	0.04	7,000,000	0.15
0.033	0.10	4,000,000	0.26
0.070	0.2	2,000,000	0.48
0.103	0.3	1,500,000	0.69
0.14	0.4	1,100,000	0.91
0.17	0.5	900,000	1.1
0.35	1.0	450,000	2.2
0.71	2.0	230,000	4.4
1.07	3.0	150,000	6.5
1.42	4.1	115,000	8.7
1.78	5.1	90,000	11.
3.56	10.3	45,000	22.
7.12	20.8	23,000	44.

Source: "Monitoring Water Quality with the Solu Bridge," A. W. Michalson, The Analyzer, February 1967.

TABLE 3-12

Water Purification Methods

Purification Method	Contaminants Removed or Function	Remarks
Distillation	Removes gross amounts of common contaminants.	Original purification method; slow; not practical for large quantities.
Activated charcoal	Removes odors, dissolved gases and residual organic material.	
Chlorination	Kills micro-organisms.	
Ultraviolet germicidal lamp	Kills exposed micro-organisms	Lamp should be checked periodically for effectiveness.
Settling	Removes coagulated materials and suspended particulate matter.	
Softening	Removes calcium, magnesium, and iron ions.	Zeolite type beds; increases sodium content and leaves neutral salts.
Demineralization	Removes cations and anions to a high-purity level.	Dual-bed for heavy contaminants; mixed-beds for lighter contaminants or combined systems.
Filtration	Removes suspended particulate and coagulated matter, and bacteria above the filter pore size.	Filters must be replaced periodically to remove contaminants and assure required volume.

TABLE 3-11

Average Hardness and pH Values of Natural Water in Selected States

State	Hardness	pH
Alabama	65	6.9
California	163	7.7
Indiana	331	7.4
Maryland	41	6.8
Massachusetts	28	6.4
South Dakota	504	8.0
Texas	219	7.8

Many water purification methods are commercially available. Again, the correct system for any one application must be determined only after considering all parameters of that application, such as the volume of water needed, the type of use (intermittent or continuous), the degree and type of purity required, site of use, and the distribution system. Various purification techniques and their functions are shown in Table 3-12.

Although other water purification techniques are commonly used to increase water purity, demineralization by ion exchange in resin beds or columns is a most effective method of producing high purity water. This method uses resins which have the property of exchanging the ions which make up water, H^+ (hydrogen) and OH^- (hydroxyl), for the dissolved mineral ions in the water. Most deionization systems can be regenerated when their supply of H^+ and OH^- ions has been exhausted. A laboratory-capacity deionizer is shown in Figure 3-3.

The electrical conductivity (and resistance) of water varies with mineral content, thus providing a readily available means of measurement and monitoring. Conductivity of water is commonly expressed in micromhos per centimeter (μmho/cm). A μmho is one-millionth of an mho, which is the reciprocal of an ohm. This property is therefore often expressed in terms of megohms per centimeter. The relative resistance and conductance values of water containing ionizable impurities are shown in Table 3-13.

The conductivity of naturally occurring water depends on the water temperature and the type and concentration of minerals present. The dissociation of water increases as the temperature rises, so that the conductivity varies with temperature. This is illustrated in Figure 3-4.

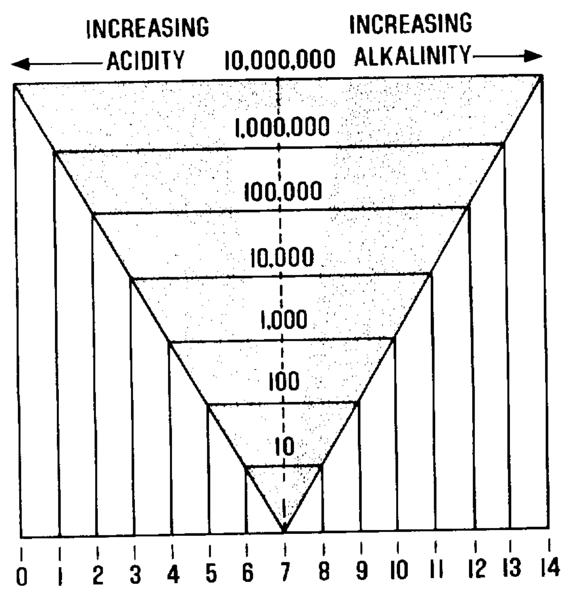
Any natural water contains several different minerals, the principal ones being calcium, magnesium and sodium bicarbonates, sulphates, and chlorides. Dissolved carbon dioxide is also usually present. Since different minerals vary in their ionization and therefore impart varying degrees of conductivity to the water, it is necessary to know the minerals present and their concentration. A list of selected elements is given in Table 3-14.

Any system for purifying water must be designed for its particular application. Each combination of system, use requirements, and water supply is unique in its characteristics. The use requirements will establish the maximum concentration of acceptable impurities. In order to determine the kind of system needed, however, the type and amounts of impurities in the locally available water must be carefully analyzed. In some cases where the mineral content is not excessive, it may be more economical to use private wells rather than the municipal water supply.

The mineral content of water is expressed in terms of "hardness," or more specifically, "grains of hardness," where one grain equals 17 ppm of calcium carbonate. Other constituents of water include silica, iron, sodium, and magnesium.

Natural water, as found in the United States, is relatively neutral. It ranges in pH value from 6.5 to 8.0. Generally, water found along the east coast is neutral or slightly acidic, while water in midwest and western parts of the country is slightly alkaline.

A pH relative strength chart is shown in Figure 3-2. A representative sample of water hardness and pH values for several states is shown in Table 3-11.



The above chart shows the relationship of pH values to relative acidities and alkalinities. The acid region is below 7 pH, the pH values decreasing with increasing acidity. The alkaline region is above 7 pH, the pH values increasing with increasing alkalinity. Note that the relative strength changes tenfold for each unit change in pH.

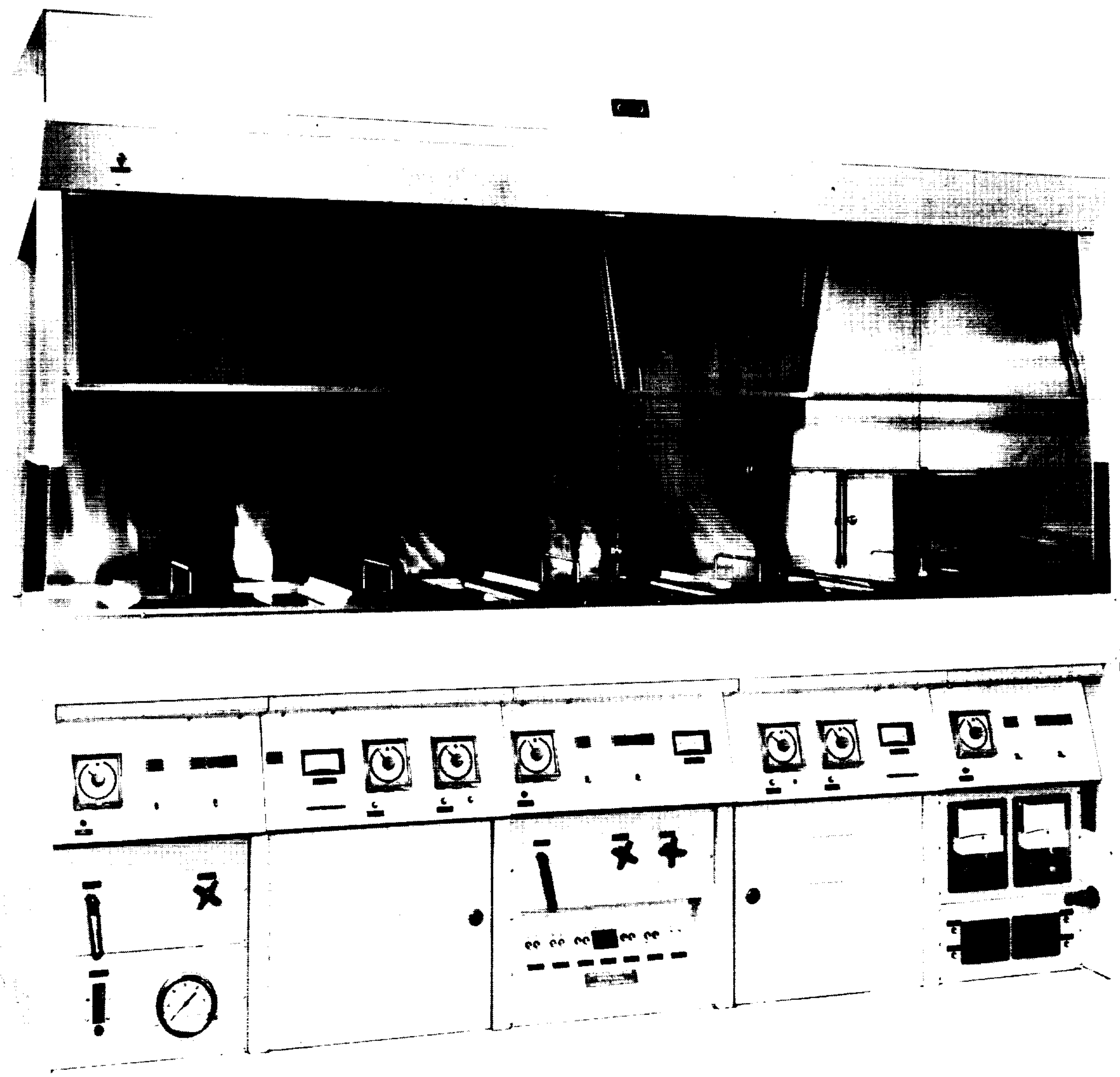
Source: Courtesty of Beckman Instruments, Inc., Fullerton, California

Figure 3-2. pH scale relative strength

c. Suspended particulate matter

d. Dissolved gases

e. Microorganisms.



Courtesy of Interlab, Inc., Pleasantville, New York

Figure 3-1. Precision cleaning station

(4) spray: widely used and effective for many soils; nozzles must be arranged so that solution hits the work piece from all sides

(5) circulating pumps: good for immersion cleaning if part configurations are compatible.

b. Movement of Parts:

(1) endless wire belts

(2) rotating drums or barrels; provides additional tumbling action

(3) oscillation or off-center rotation of suspension rods; parts must be racked or in baskets

(4) hydraulically activated baskets; basket is an integral part of the washer; surging action provided by lowering and raising basket into and out of solution.

3.4 Precision Cleaning

The term precision cleaning has not been clearly defined; however, a high degree of surface cleanliness is implied. The degree may vary from absolute visual cleanliness to less than one molecular layer of soil.

As the need for cleanliness increases, so does the need for high purity solvents, closely controlled techniques, clean environments, and more sensitive test methods. An example of some of these features is shown in the combined multistage cleaner/ laminar flow bench in Figure 3-1.

3.4.1 High Purity Water

Among its other vital uses, water has always been known to man as a washing agent. Today, large quantities of high purity water are needed by industry in chemical production, parts rinsing, and cleaning operations. Although water is often considered as a rinsing medium and is frequently used for this purpose, high purity water is also a highly effective solvent for some soils.

In its natural state, water contains many impurities which inhibit or preclude its use for industrial purposes. The types and concentrations vary widely with different geographical areas but can generally be classified as:

a. Dissolved mineral matter

b. Organic matter

TABLE 3-10

Comparison of Washer Filtration Methods

Type of Removal and Disposal	Method and Effectiveness	Relative Cost Considerations
Solution replacement	Entire solution discharged and replaced; varying degree of cleanliness from very good to poor.	Nominal for light cleaning; generally costly in solution and heat consumption, and loss of production time.
Centrifuging and filtering	Effective for many soils, but requires sizeable installation for high flow rates.	High first cost and maintenance.
Edge strainers	Overflow principle; can handle large quantities of top-floating material.	Minimal solution loss; one of least costly methods.
Sludge conveyor	Bars scrape tank bottom and deposit soils in sludge tank; good for heavy insoluble particles.	Nominal first cost; minimum maintenance cost.
Belt filter	Roll filter material lays on top of conveyor, under spray chamber; effective to 20 microns.	Reasonable cost for this type of filtration.
Fine filtering system	Very effective for selected or all soils to low micron size; usually a special attachment to washer.	High first and operating cost; must be justified by requirements.

b. Two-Stage:

(1) usually spray or paddle wheel type

(2) one stage may be a rinse or dry operation.

c. Multistage:

(1) conveyorized using rollers, endless wire-mesh belts, flight bars, monorails or spiral rotating drums

(2) normally includes several washes, plus rinsing and drying

(3) high quantity production

(4) many combinations of washing methods and equipment available.

Cleaning agents are discussed in detail in Paragraph 3.5. Detergent, acid, alkaline, and solvent solutions are available for industrial washing applications. It is sound practice to consult materials, contamination control, and processing specialists, as well as manufacturers' representatives, in planning the cleaning agent and type of operation to be employed.

Since the purpose of washing is to remove unwanted soils, it is equally important that these soils be removed from the solution to prevent redeposition on the work piece. In the case of spray equipment, accumulated soil will also clog the spray nozzles.

The relative merits of various filtration methods are shown in Table 3-10.

3.3.4.2 Agitation

Many factors such as solution chemistry, heat, time, and agitation are important to effective and economical parts cleaning. The subject of agitation is sometimes relegated to minor importance but is, in effect, a most important consideration. Agitation provides the functions of soil removal by physical action, carrying the soil away from the parts, and in some cases, furnishing a fresh supply of solvent to the parts. Some of the conventional means of achieving agitation are listed below:

a. Movement of Solution:

(1) boiling the solution: sets up convection currents, but not recommended for all solutions

(2) compressed air: provides solution movement, but may cause excessive foaming especially with detergent-type solutions

(3) paddles: provide a continuous large volume of cleaning solution to the parts at a low pressure; simple yet effective, especially for fine particles and chips

d. Steam -- Pressurized steam is effective for removal of heavy oils, grease, and sludge deposits as well as most shop dirt. Ferrous metals will oxidize rapidly after steam cleaning if they are not protected.

e. Chipping -- Manual chisel and hammer operation for removing excessive weld beads, heavy weld spatter, and scale.

f. Wiping -- Usually limited to dirt, oils, and grease to prevent contamination of subsequent and more precision cleaning processes. Solvent-saturated wiping cloths are generally used.

3.3.4 Washers

Industrial or parts washers are used to remove and dispose of contamination which would be deleterious to further processing or to the end use of the product.

3.3.4.1 Types of Washers

The combination of types of washers and cleaning solutions available is nearly unlimited, but some of the standard size types will be described in this section. Because of the variety of cleaning situations encountered, many washing operations are custom-designed to fit process needs. It is extremely important in planning a cleaning function of this type, as with all cleaning, to consider the parameters shown in Table 3-1.

Parts washers are characterized by various features, some of which are:

a. Work piece size or volume capacity

b. Type of washing action or agitation

c. Number and types of stages

d. Degree of automation

e. Type of part conveyance

f. Type and capacity of filtration system.

Commercial nomenclature for parts washers includes the following general types:

a. Single Stage:

(1) uses immersion, spray or steam as cleaning method

(2) manual or automated operation

(3) usually used for batch or small quantity production.

gauntlet gloves, as well as appropriate leg and ankle protection. In the case of dry blasting, all necessary precautions should be taken against the possibility of operators contracting silicosis.

TABLE 3-9

Comparison of Wet and Dry Abrasive Blasting Methods

	Wet	Dry
Type of force used	Compressed air	Compressed air High-speed mechanical blower
Abrasive media	Aluminum oxide Garnet Quartz Novaculite Silica Organic materials Glass beads	Metallic shot Metallic grit Aluminum oxide Garnet Quartz Novaculite Silica Organic materials Glass or plastic beads
Typical types of soils removed	Light rust Surface oxides Light mill scale Welding scale	Rust Mold sand Mill and heat-treat scale Welding flux Paint Carbon Weld spatter

3.3.3 Mechanical Cleaning

Soil removal by mechanical means, although not usually considered to be a contamination control process, does have its place in the removal of gross soils. Abrasion or erosion is employed as the means of soil removal.

Some of the more common mechanical cleansing methods are:

a. Grinding Wheels -- Used on portable or stationary grinders to remove heavy weld spatter, flash, and scale. Disc or belt sanders may be used for lighter soils.

b. Wire Brush -- Either manual or power brushes are used for removal of weld scale and light oxides; not recommended for titanium.

c. Rasp Files -- Manual operation for heavy metallic soils.

Although other cleaning methods are generally used for the removal of oil and grease, barrel cleaning can be used for this purpose. Cleaning action is provided by an alkaline solution, solvent or emulsions, or a suitable combination of the three.

Barrel descaling is more commonly used than barrel cleaning. Acid compounds are usually preferred for their faster action, and may be supplemented by wetting agents and abrasives.

Dry tumbling is a means for gross cleaning castings and forgings. Mill scale, sand, and hardened mold release materials are effectively removed by this method. After tumbling, the work must be removed from the medium. Magnetic separating devices may be used for ferrous parts and reciprocating or vibrating screens for nonferrous parts.

To achieve the best results from barrel cleaning, the following factors must be considered:

a. Barrel Speed -- Proper speed to regulate part movement without incurring centrifugal force sufficient to hold parts on the barrel surface

b. Compound -- Proper for application; noncorrosive; maintained at adequate concentration

c. Water Level -- Sufficient to prevent excessive tumbling without completely filling barrel

d. Medium -- Correct material, size, shape, and quantity to provide desired scrubbing or abrasive action

e. Work Pieces -- Proper size to be accommodated by the barrel, configuration to prevent interlocking, and composition

f. Flushing -- Parts and barrel should be flushed after tumbling to remove objectionable residues.

3.3.2 Abrasive Blast Cleaning

Abrasive blast cleaning involves the forceful impingement of abrasive particles against a metal surface to remove unwanted soils. The particles are impelled toward the work surface by compressed air or by means of a high-speed bladed wheel. Both wet and dry processes are available. These are compared in Table 3-9.

Abrasive blast methods are commonly known by the type of abrasive they use, i.e., sand blasting, grit blasting, and glass-bead blasting. Blast methods also employ the use of organic abrasives such as crushed corncobs, rice hulls, and walnut shells for milder abrasive action.

Protective apparel and apparatus for personnel operating abrasive blasting equipment are essential. These should include a suitable combination of safety glasses, an independent air supply, protective helmet with air supply, abrasive-resistant aprons, and

TABLE 3-8
(continued)

Environments	Brass and Naval Bronze	Silicon Bronze	Monel Metal	Stainless Types 410, 416, and 430	Stainless Types 302, 303, 304, and 305	Stainless Type 316	Copper	Aluminum
Rosin (dark)	G	G	E	E	E	E	G	F
Rosin (light)	NG	NG	G	E	E	E	NG	G
Shellac	G	E	E	E	E	E	E	E
Soda ash (sodium carbonate)	G	G	E	E	E	E	E	NG
Sodium bicarbonate	E	E	E	E	E	E	E	G
Sodium bisulfate	F[1]	G	E	NG	NG	E	G	F
Sodium chloride	F	G	E	F	G	E	G	G
Sodium cyanide	NG	NG	G	E	E	E	NG	NG
Sodium hydroxide	NG	F	E	E	F	E	F	NG
Sodium hypochlorite	NG	F	F	NG	F	G	F	NG
Sodium metaphosphate	F	G	E	G	E	E	G	F
Sodium nitrate	F	G	E	E	E	E	G	E
Sodium perborate	F	G	E	E	E	E	G	F
Sodium peroxide	F	G	E	E	E	E	G	F
Sodium phosphate (alkaline)	F	G	E	E	E	E	G	NG
Sodium phosphate (neutral)	G	E	E	E	E	E	E	NG
Sodium phosphate (acid)	F[1]	G	E	NG	G	E	G	NG
Sodium silicate	F	G	E	E	E	E	G	G
Sodium sulfate	G	E	E	E	E	E	E	E
Sodium sulfide	NG	NG	G	E	E	E	NG	NG
Sodium thiosulfate (hypo)	NG	NG	G	E	E	E	NG	E
Sludge acid	NG	G	G	NG	NG	F	G	NG
Stearic acid	F[19]	G[24]	E	G[20]	G[20]	E	G[24]	E
Sulfate liquors	NG	NG	G	E	E	E	NG	NG
Sulfur	F	F	F	E	E	E	F	E
Sulfur chloride	NG	NG	G	NG	F	G	NG	NG
Sulfur dioxide (dry)[9]	F	E	E	E	E	E	E	G
Sulfur dioxide (wet)	NG	G	NG	NG	G	E	G	F
Sulfuric acid 10%	NG	G[25]	G[25]	NG	NG	G[25]	G	NG
Sulfuric acid 10%, 75%	NG	F	G	NG	NG	NG	F	NG
Sulfuric acid 75%, 95%	NG	F[26]	F[26]	F[27]	F[27]	G[27]	F[26]	NG
Sulfuric acid 95%	NG	G	NG	G	G	G	NG	F
Sulfurous acid	NG	G	NG	NG	F	G	G	NG
Tar	G	E	E	G	E	E	E	E
Tartaric acid	F[1]	G	G	F	G	E	G	G
Toluene or toluol[8]	E	E	E	E	E	E	E	E
Trichloroethylene[12]	E	E	E	E	E	E	E	E
Turpentine	F[28]	E	E	G[28]	E	E	E	E
Varnish[29]	G	G	E	E	E	E	G	E
Vegetable oils[29]	G	G	E	E	E	E	G	E
Vinegar[25]	NG	G	G	F	G	E	G	E
Water (acid mine water)	NG	30	30	31	31	31	30	F
Water (fresh)	F[32]	G	E	E	E	E	G	E
Water (salt)	F[32]	G	E	F[33]	G[33]	G[33]	G	G
Whiskey	G	G	G	F	E	E	G	F
Wines	G	G	G	F	E	E	G	F
Xylene or xylol[8]	E	E	E	E	E	E	E	E
Zinc chloride	NG	G	E	NG	NG	G	G	NG
Zinc sulfate	F	G	E	F	G	E	G	G

TABLE 3-8

(continued)

Environments	Brass and Naval Bronze	Silicon Bronze	Monel Metal	Stainless Types 410, 416, and 430	Stainless Types 302, 303, 304, and 305	Stainless Type 316	Copper	Aluminum
Ferric sulfate	NG	F	F	E	E	E	F	G
Formaldehyde	G	G	E	E	E	E	G	G
Formic acid	F[1]	G	G	NG[2]	G	E	G	NG
Freon	E	E	E	E	E	E	E	G
Furfural	G	G	E	E	E	E	G	E
Gasoline (sour)	F	NG	NG	F	E	E	NG	NG
Gasoline (refined)	E	E	E	E	E	E	E	E
Gelatin	F[13]	E[13]	E	F[13]	E	E	E[13]	E
Glucose	E	E	E	E	E	E	E	E
Glue	F	E	E	E	E	E	E	F
Glycerine or glycerol	G	E	E	E	E	E	E	E
Hydrochloric acid	NG	F[14]	F[14]	NG	NG	NG	F[14]	NG
Hydrocyanic acid (hydrogen cyanide)	NG	NG	G	F	E	E	NG	E
Hydrofluoric acid	NG	F	E	NG	NG	NG	F	NG
Hydrogen fluoride	F	G	E	F	G	G	G	NG
Hydrogen[9]	E	E	E	E	E	E	E	E
Hydrogen peroxide	NG	F	G	E	E	E	F	G
Hydrogen sulfide (dry)	F[6]	NG[6]	F[6]	G	E	E	NG[6]	E
Hydrogen sulfide (wet and aqueous solution)	F	NG	F	F[15]	G	E	NG	E
Lacquers and lacquer solvents	F	E	E	E	E	E	E	E
Lime-sulfur	NG	F	G	G	E	E	F	NG
Magnesium chloride	F	G	E	F	G	E	G	NG
Magnesium hydroxide	G	E	E	E	E	E	E	F
Magnesium sulfate	G	E	E	E	E	E	E	G
Mercuric chloride	NG	NG	NG	NG	NG	F[16]	NG	NG
Mercury	NG	NG	G	E	E	E	NG	NG
Milk	F	F	F	G	E	E	F	E
Molasses	G	E	E	G	E	E	E	E
Natural gas	G	E	E	E	E	E	E	E
Nickel chloride[17]	NG	F	G	NG	F	G	F	NG
Nickel sulfate[17]	F	G	E	F	G	E	G	NG
Nitric acid	NG	NG	NG	G[18]	G	G	NG	F
Oleic acid	F[19]	G[24]	E	G[20]	G[20]	E	G[24]	E
Oxalic acid	F[1]	G	E	F	G	E	G	NG
Oxygen[9]	E	E	E	E	E	E	E	E
Palmitic acid	F[19]	G[24]	E	G[20]	G[20]	E	G[24]	E
Petroleum oils (sour)	F	NG	NG	F	E	E	NG	NG
Petroleum oils (refined)	E	E	E	E	E	E	E	E
Phosphoric acid 25%	NG	G[21]	G[22]	NG	F[23]	E	G[21]	NG
Phosphoric acid 25%, 50%	NG	G[21]	G[22]	NG	NG	G	G[21]	NG
Phosphoric acid 50%, 85%	NG	G[21]	G[22]	NG	NG	G	G[21]	E
Picric acid	NG	NG	NG	G	E	E	NG	F
Potassium chloride	F	G	E	F	G	E	G	NG
Potassium hydroxide	NG	F	E	E	E	E	F	NG
Potassium sulfate	G	E	E	E	E	E	E	E
Propane[9]	E	E	E	E[10]	E[10]	E[10]	E	E

TABLE 3-8
Corrosion Guide

Environments	Brass and Naval Bronze	Silicon Bronze	Monel Metal	Stainless Types 410, 416, and 430	Stainless Types 302, 303, 304, and 305	Stainless Type 316	Copper	Aluminum
Acetate solvents, crude	F	G	G	G	E	E	G	E
Acetate solvents, pure	E	E	E	E	E	E	E	E
Acetic acid, crude	F[1]	G	G	NG[2]	G	E	G	G
Acetic acid (pure)	F[1]	G	G	NG[2]	G	E	G	E
Acetic acid vapors	NG	G	F	NG	G	E	G	E
Acetic anhydride	NG	G	G	NG	G	E	G	E
Acetone	E	E	E	E	E	E	E	E
Acetylene	3	NG	G	E	E	E	NG	E
Alcohols	G	E	E	E	E	E	E	G
Aluminum sulfate	F[1]	G	G	NG	F	G	G	F
Alums	F[1]	G	G	NG	F	G	G	E
Ammonia gas[4]	NG[5, 6]	6	6	E	E	E	6	E
Ammonium chloride	F[1]	G	E	F	F	E	G	NG
Ammonium hydroxide	NG	NG	F	E	E	E	NG	G
Ammonium nitrate	NG	F	F	E	E	E	F	E
Ammonium phosphate (ammoniacal)	NG	NG	G	E	E	E	NG	NG
Ammonium phosphate (neutral)	F	F	G	G	E	E	F	F
Ammonium phosphate (acid)	F[1]	F	G	F	G	E	F	F
Ammonium sulfate	F[1]	F	G	G	E	E	F	G[35]
Asphalt	G	E	E	G	E	E	E	E
Beer	G	G	E	7	E	E	G	E
Beet sugar liquors	G	E	E	G	E	E	E	E
Benzene or benzol[8]	E	E	E	E	E	E	E	E
Benzine[8]	E	E	E	E	E	E	E	E
Borax	G	G	E	E	E	E	G	G
Boric acid	F[1]	G	E	F	G	E	G	E
Butane, butylene, butadiene[9]	E[34]	E[34]	E	E[10]	E[10]	E[10]	E[34]	E
Calcium bisulfite	NG	G	NG	NG	G	E	G	NG
Calcium hypochlorite	F	F	F	NG	F	G	F	NG
Cane sugar liquors	G	E	E	G	E	E	E	E
Carbon dioxide (dry)	E	E	E	E	E	E	E	E
Carbon dioxide (wet) and (aqueous solution)	F[11]	G[11]	G[11]	E[11]	E	E	G[11]	E
Carbon disulfide	F	NG	F	G	E	E	NG	E
Carbon tetrachloride[12]	E	E	E	E	E	E	E	G
Chlorine (dry)	G	G	E	G	G	G	G	NG
Chlorine (wet)	NG	F	F	NG	NG	F	F	NG
Chromic acid	NG	NG	F	F	G	E	NG	NG
Citric acid	F[1]	G	G	F	G	E	G	G
Coke oven gas	F	F	G	E	E	E	F	G
Copper sulfate	NG	F	F	E	E	E	F	NG
Core oils	E	E	E	E	E	E	E	E
Cottonseed oil	E	E	E	E	E	E	E	E
Creosote	F	G	E	E	E	E	G	G
Ethers	E	E	E	E	E	E	E	E
Ethylene glycol	G	E	E	E	E	E	E	G
Ferric chloride	NG	NG	NG	NG	NG	NG	NG	NG

Corrosion Guide Notes for Table 3-8

Corrosion resistance of metals designated by: E - Excellent, G - Good, F - Fair, NG - No Good

1. Subject to dezincification and/or stress corrosion, especially at elevated temperatures and with concentrated solutions.
2. May be useful with cold dilute acid.
3. Alloys containing up to 60-percent copper acceptable; high copper alloys not acceptable.
4. Temperature assumed to be below that at which gas cracks and liberates nascent nitrogen.
5. Subject to stress corrosion with low concentrations.
6. Apparently resistant to dry gas at ordinary temperatures; attacked rapidly by moist gas and by hot gas.
7. Not recommended for use with beverage grade.
8. Chemicals used for treating in manufacture assumed to be absent.
9. Temperature assumed to be no higher than that normally encountered in compression, storage, and distribution.
10. Useful at elevated temperatures.
11. Not recommended for use with carbonated beverages.
12. Water assumed to be absent.
13. Not recommended for use with edible grades.
14. Only with dilute or unaerated solutions.
15. Subject to stress corrosion by moist gas, and to severe general corrosion by saturated aqueous solution.
16. Subject to stress corrosion.
17. None of these materials recommended for use with nickel-plating solutions.
18. Higher chromium alloys (over 18 percent) preferred.
19. Not recommended for temperature over 100°C (212°F).
20. Alloys with less than 18% Cr not recommended for temperatures over 100°C (212°F). Others not recommended for temperatures over 200°C (390°F).
21. Up to 60°C (140°F).
22. Up to 90°C (200°F).
23. At room temperature.
24. Not recommended for temperatures over 200°C (390°F).
25. Nonferrous alloys preferred when unaerated and at temperatures above normal. Stainless steel best when aerated and at normal to moderate temperatures.
26. With cold acid only.
27. In the absence of exposure to moist air.
28. Crude produce may contain acids which corrode these materials.
29. Some of these ratings may not apply when handling light-colored products at elevated temperatures (200°C) (390°F).
30. Good with water containing no oxidizing salts; fair with water containing oxidizing salts.
31. Excellent with water containing oxidizing salts; not good with water containing no oxidizing salts.
32. Subject to dezincification with hot and/or aerated waters.
33. Subject to pitting attack
34. Copper may act as a catalyst for undesirable reactions.
35. Free sulphuric acid absent.

Source: Harper, H. M. Co., Corrosion Guide, Tech. Bul. No. 101

TABLE 3-7

Special Cleaning Methods to Remove Corrosion Products

Metal	Aqueous Solution	Temperature (°C)	Operation
Aluminum alloys	Nitric acid 75 percent	25	2 to 3 min immersion, then light scrubbing with bristle brush and rinse.
Copper and nickel alloys	Hydrochloric acid 18 percent or sulphuric acid 10 percent	25	2 to 3 min immersion, then scrub with bristle brush and rinse.
Iron and steels (except stainless steels)	Ammonium citrate 10 percent	25	Cathodic treatment with cathode current density at 1 amp/in.^{2} - time dependent on corrosion products. Rinse.
	Sodium cyanide 10 percent	20	Cathodic treatment for 20 min with cathode current density at 1.5 amp/in.^{2}. Rinse.
	Sodium hydroxide 20 percent with 200 grams per liter zinc dust.	Boiling	5 min immersion and rinse.
Stainless steels	Nitric acid 10 percent	60	Immersion followed by rinse. Time dependent on corrosion product. (Contamination with chlorides may attack base metal.)
Lead alloys	Acetic acid 1 percent	Boiling	10 min immersion, then scrub lightly and rinse.
	Ammonium acetate 25 percent	90-100	Immersion, then scrub lightly and rinse. Time dependent on corrosion product.
Magnesium alloys	Chromic anhydride 15 percent with silver chromate 1 percent	Boiling	15 min immersion, then rinse. (Contamination with chlorides and sulfates may attack base metal.)
Tin alloys	Trisodium phosphate 15 percent	Boiling	10 min immersion, then scrub lightly with bristle brush and rinse.
Zinc alloys	Ammonium chloride 10 percent Solution 1	60-80	5 min immersion in Solution 1, then scrub lightly with bristle brush and rinse. Followed by 20-sec immersion in Solution 2, and rinse. (Contamination with chlorides and sulfates may attack base metal.)
	Chromic acid 5 percent with silver nitrate 1 percent Solution 2	Boiling	
All the above metals	Sulphuric acid 5 percent with 0.5 gram per liter of one of the following: quinoline ethiodide, diorthotolyl thiourea, betanaphthol.	75	Cathodic treatment for 3 to 5 min with cathode current density at 1.3 amp/in.^{2} then rinse. (Carbon anode preferred.)

Special cleaning methods for specific materials have been developed that are quite effective; however, the metals so cleaned should be well rinsed in running water to remove all traces of the solution and then dried. The solutions for cleaning specific metals are shown in Table 3-7.

3.2.2 Corrosion Guide

The selection of materials suitable for a given environment should be one of the first considerations in product design. Certain metals and metal alloys are more resistant to some corrosive environments than others. A group of these metals together with a listing of corrosive environments that may be encountered are shown in Table 3-8, with relative resistance to the corrosive environments for each metal. This is a general guide only and specific conditions may require further investigation and analysis for selection of the best material.

The following references are considered a basis for further study and detailed analysis of specific problems in corrosion and corrosion control.

References:

Uhlig, The Corrosion Handbook, Wiley & Sons (1948).

Shreir, Corrosion Vol. 1 and 2, Wiley & Sons.

Baumeister, Mechanical Engineers Handbook, 6-121, McGraw-Hill (1958).

Perry, Chemical Engineers Handbook, 23, McGraw-Hill (1963).

3.3 Gross Cleaning

Gross or rough cleaning may not be normally associated with contamination control as it applies to space hardware. It is, however, often the first cleaning step in a comprehensive contamination control program. Inadequate removal of gross soils can lead to subsequent degradation of precision cleaning solutions or the failure to completely remove certain soils.

It is recognized that some of the gross cleaning methods discussed in this section are also considered surface preparation treatments. While this duality of function exists, this document is concerned primarily with the contamination control aspects.

3.3.1 Barrel Cleaning

Barrel cleaning is accomplished by the tumbling action of parts and a medium within a rotating enclosure. The process may be used either wet or dry and with a variety of media for the removal of different soils. The amount of tumbling action varies inversely with the total mass of parts and media in the barrel. The total mass is usually set at 50 to 90 percent of the barrel volume.

TABLE 3-5

Corrosion Control Considerations During Product Design

Factors	Means
Materials	Select materials suitable for given environmental conditions.
Dissimilar metals in contact	Avoid designs in which the kinetics of attack on one metal are stimulated by another.
Configuration (geometry)	Avoid designs which lead to localized attack, impingement, cavitation, etc.
Mechanical	Avoid excessive stress (internal or applied) when using metals susceptible to stress-corrosion cracking. Avoid conditions leading to corrosion fatigue and fretting corrosion.
Surface	Avoid conditions on surfaces which lead to localized attack such as discontinuous films of oxides or metals.
Protection	Provide for cathodic or anodic protection. Provide for applying protective coatings.

TABLE 3-6

Corrosion Control Methods

Areas	Methods
Design and procedure	Materials, configuration, surfaces, etc. (see Table 3-5). Application of cathodic protection. Application of cleaning procedure.
Environments	Deaeration of water or neutral solution. Purification or dehumidification of air. Addition of corrosion inhibitors. Reduction in temperature.
Metals	Increased purity. Addition of alloying elements. Heat treatment.
Protective coatings	Chemical or electrochemical treatment of metal surfaces. Organic coatings: paints, resins, etc. Inorganic coatings: enamels, cements. Metal coatings. Temporary protectives.

(4) sand blasting

(5) ultrasonic (sonic).

b. Chemical

(1) organic solvents

(2) chemical reagents.

c. Electrolytic

(1) sulphuric acid

(2) citric acid

(3) potassium cyanide

(4) caustic soda.

TABLE 3-4

Galvanic Series Chart

Anode - Least Noble (corroded end)

Magnesium	Brass
Magnesium alloys	Copper
Zinc	Bronze
Aluminum 1100	Copper-nickel alloys
Cadmium	Monel
Aluminum 2024-T4	Silver solder
Steel or iron	Nickel (passive)
Cast iron	Inconel (passive)
Chromium-iron (active)	Chromium-iron (passive)
Ni-resist	Titanium
Stainless Type 304 (active)	Stainless Type 304 (passive)
Stainless Type 316 (active)	Stainless Type 316 (passive)
Lead-tin solders	Hastelloy alloy C (passive)
Lead	Silver
Tin	Graphite
Nickel (active)	Gold
Inconel (active)	Platinum
Hastelloy alloy C (active)	

Cathode - Most Noble (protected end)

TABLE 3-3

Types of Corrosion

Type	Description
Uniform or General	Purely chemical attack or anodic-cathodic reaction in which the anode and cathode separation is not distinguishable, resulting in uniform loss of metal on the exposed surface. Forms of this type include: oxidation at high temperature, tarnish, rust, fogging, etc.
Localized or Cell	Anodic-cathodic reaction where the anodes and cathodes are distinguishably separate, resulting in loss of metal at localized anodic areas called pitting. Forms of this type include crevice, channel, and pocket corrosion wherein a concentration of the electrolyte may be confined or restricted, stimulating corrosion action. This type is also accelerated by erosion actions such as fretting, impingement, and cavitation, which remove the normally protective film of corrosion products.
Selective or Dezincification	Anodic-cathodic reaction in alloys where the anodic constituent is removed leaving a porous residue of the cathodic constituents, such as: the removal of zinc from brass alloys, parting of noble metals (silver and gold) and graphitic corrosion of grey cast iron.
Intergranular	Localized type of anodic-cathodic reaction that occurs and progresses preferentially along the grain boundaries of an alloy due to the boundary region material being more anodic with respect to the central region of the grains. This type corrosion occurs in austenitic stainless steel, during welding in the base metal adjacent to the deposited metal, as a result of localized impoverishment of chromium at grain boundaries, and at grain boundaries in some acidic environments.
Stress or Cracking	Combined effects of residual or applied stress and uniform or localized corrosion action. This type includes corrosion fatigue which occurs under dynamic or alternating stress conditions in a corrosive environment.
Galvanic	Anodic-cathodic reaction between two metals of different potential in contact in an electrolyte with the anodic metal being dissolved. The severity of the reaction depends on the difference in potential of the two metals and the relative surface areas involved. Corrosion of the anodic metal is greater when the cathodic metal area is increased or the potential difference is increased. See Table 3-4 for galvanic series of metals.
Stray Current or Electrolysis	Electric currents which stray from the intended circuit and follow paths through an environment such as soil or water and through a metal object seeking a return path to the circuit, cause anodic reaction at the points of exit from the metal. The severity of this type corrosion is dependent on the intensity of the current and voltage. Currents of extremely feeble intensity and voltage may serve to accelerate corrosion, when not having initiated it.
Microbiological	Corrosion processes which occur, either directly or indirectly, as a result of the metabolic activity of microorganisms. They contribute to corrosion by one or more of the following factors dependent upon the physiological characteristics of the microorganism. a. Direct influence on the rate of anodic-cathodic reaction. b. Change of surface metal films resistance by metabolism or products of metabolism. c. Creation of corrosive environment. d. Establishment of a barrier by growth and multiplication so as to create electrolytic concentration cells on the metal surface. Microorganisms most frequently involved in direct metabolic activity are the anaerobic sulfate-reducing bacteria. The aerobic bacteria and/or fungi contribute principally by providing environments conducive to anaerobic bacteria development.

(3) liquids

(4) soils

(5) contact with dissimilar metals (galvanic)

(6) stray electrical current.

Corrosion occurs in various forms as affected by the many variations in metals and environments plus the mechanics involved. In order to recognize the significant forms normally encountered, corrosion is classified into basic types with respect to outward appearance, altered physical properties, or reactions produced.

Table 3-3 lists these basic types with a description of the mechanisms and reactions involved.

Galvanic coupling of two dissimilar metals in an electrolyte produces a current flow called galvanic current. The source of energy manifested as galvanic current is primarily the dissolution of the anodic metal. The relative position of various metals and alloys as related to their anodic-cathodic potentials is shown in the galvanic series chart, Table 3-4.

Galvanic corrosion can be used to minimize corrosion in selected metals by making the metal to be protected the cathode in the electrolyte involved.

3.2.1 Corrosion Control

Methods for the control of corrosion and corrosion products must be considered in product design, with relation to the effects on material and contamination of product. Factors to be considered and means of control are shown in Table 3-5.

Selection of control methods, that are consistent with the economic and technological factors involved, requires consideration of the areas in which the various methods are most effective. Table 3-6 lists the areas for consideration and typical methods for control in each area.

The removal of corrosion products from the metal surface may be required in preparation for protective coatings or in the elimination of potential contaminants. A variety of cleaning methods may be used; however, whatever method is employed, its effect in removing the base metal should be determined for each material. Each method possesses certain advantages and disadvantages; therefore, a combination of methods may provide the best results commensurate with the performance requirements. Methods for removing corrosion products are classified as follows:

a. Mechanical

(1) scrubbing with bristle brush

(2) scraping

(3) wire brushing

TABLE 3-2

Comparison of Cleaning Method Effectiveness for Soil Removal

Cleaner or Cleaning Method	Pigmented Drawing Compounds	Unpigmented Oil and Grease	Chips[3] and Cutting Fluids	Polishing and Buffing Compounds	Rust and Scale[4]
Emulsion	Emulsified solvent better than emulsions alone; good for this type soil.	Precleaner or preparation for other operations— not preferred as primary cleaner.	Combined immersion and spray effective; often used after alkaline; check pH.	Used on ferrous and some nonferrous materials. Effective if sprayed on most compounds; should be rinsed.	Not recommended.
Alkaline	Generally marginal; more effective with spray, agitation, or impingement.	Efficient for most soils; must have good rinse; must be inhibited for non-ferrous.	Effective and economical; must be inhibited for non-ferrous.	Widely used and least costly; agitation or spray with surfactant recom-mended.	Removes rust, light scale; no metal loss or hydrogen embrittlement.
Acid[1]	Effective for dried compounds, with water and spray.	Good for this soil; often used with spray; some form protective coating; etch nonferrous.	Effective when used with power spray.	Generally not recom-mended, except for newly applied, easily removed compounds.	Removes rust on ferrous metal parts; acid pickling removes mill scale.
Electrolytic Alkaline	Not recommended; may be used as final cleaning after other methods.	Produces very clean sur-faces; usually final cleaner prior to electro-plating.	Recommended for high cleanliness levels; also good final cleaning.	Used after precleaning; tendency to contaminate solution.	Faster than alkaline baths; parts require racking; can remove other soils in one operation.
Solvent[2]	Generally not suita-ble; sometimes used as precleaner.	Primarily precleaning; effectiveness increased by spray, agitation, and scrubbing.	Immersion, agitation, and spray effective with sol-vent soluble soils.	Soak, spray, or brush with solvents is effective as a precleaner.	Not recommended.
Vapor Degreasing[2]	Limited value; more effective with dip, spray, ultraonic com-binations.	Very effective; wide range of uses; repeatable; parts immerge dry.	Good only for solvent soluble soils; used with immersion, spray, and air blowoff.	Compound may bake on unless spray precedes vapor phase.	Not recommended.
Ultrasonic	Effective if properly used, but more costly.	Very effective for remov-ing this type soil on small or precision components.	Effective for some soils; guard against chip accu-mulation.	Generally used as final cleaner on intricate or precision parts.	May remove light rust or scale from small or com-plex parts.

1. Acid cleaning is effective with many types of soils but is generally more costly than other equally effective methods.
2. Since vapor degreasing utilizes solvents, these two methods are similar. Some solvents, however, are not suitable for vapor degreasing.
3. Soils bonding chips to parts can be removed by these methods, but physical force such as gravity, spray, agitation, etc., may be needed to remove the chips from the part.
4. In removing rust and scale, other methods such as pickling, salt bath, brushing, abrasive blast, and tumbling should be considered.

Table 3-2 presents a general comparison between some of the common surface soils and the effectiveness of cleaning agents and methods in removing them. More detailed information on specific soils and their removal is found in the following sections of this handbook.

3.2 Corrosion

Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Deterioration of a metal by physical causes such as galling or wear is called erosion. Chemical attack when accompanied with physical deterioration is defined as corrosion-erosion, or fretting corrosion.

Direct chemical corrosion is limited to unusual conditions involving highly corrosive environments or high temperature or both. However, most of the phenomena involving corrosion of metals is electrochemical in nature.

Electrochemical corrosion is the anodic and cathodic reaction with an electrolyte normally provided in the environment to which the metal is exposed. Anodic reaction takes place when the metal dissolves in the electrolyte in the form of positively charged ions. Cathodic reaction occurs when positively charged hydrogen ions plate out as atomic hydrogen on the cathodic surface. The electrons released by the anodic reaction flow through the metallic circuit to the cathode to neutralize an exactly equivalent number of hydrogen ions. The hydrogen film will eventually cover and polarize the cathodic surface, stopping the flow of electrons. The positive metal ions released near the surface of the anode combine with negative hydroxide ions from the electrolyte (water) to form a neutral metal hydroxide which may coat the anodic surface stopping the ion release. Thus, under favorable conditions, the electrochemical reaction will stifle itself at the cathode or anode or both.

Metal corrosion being the reaction of metal with the environment, the rate and type of corrosion that occurs are affected by the many variations of these two factors which include:

a. Metal Properties

(1) structure and orientation

(2) composition including alloy components and impurities

(3) surface condition and finish

(4) metal stresses, applied and internal.

b. Environment

(1) temperature

(2) atmospheric: humidity, dust, and gases

TABLE 3-1

Engineered Cleaning System

Considerations for Analysis of Cleaning System Requirements						
Environment	Cleaning Agent			Equipment		
Cleanliness Level	Reason for Cleaning	Soil to be Removed	Materials of Construction	Configuration	Work Load	Method or Technique
Outdoors Factory Laboratory Glove box Fume hood Clean bench Clean room	Function Reliability Surface preparation Maintenance Appearance	Organic: Oil Grease Wax Microbial Inorganic: Salts Compounds Rust Scale Fines	Nonferrous metals Ferrous metals Alloys Plastics Elastomers Glass Paints Inks Combinations	Flat surfaces Convolutions Blind holes Crevices Material mass Fasteners	Part size Quantity Type(s) of soil Manual Automated	Dip Soak Flush Wipe Spray Electrolysis Vapor degrease Ultrasonic Combinations ------------ Monitoring

amount may actually be effective in removing soil. In the formula of a scientifically balanced detergent, the choice of each component can be justified in terms of the definite function assigned to it in the cleaning operations. Moreover, the components should not merely fulfill their individual functions, but should support and reinforce each other, so that the whole compound will be more active and more stable than any of its parts.

k. Hard Versus Soft Water -- If distilled water could be used in the makeup of aqueous cleaning solutions, many problems could be avoided. It is, unfortunately, impractical to use distilled water in the tremendous gallonage required for industrial cleaning operations. Local natural water sources are employed, and these almost invariably contain dissolved bicarbonates and sulphates of calcium and magnesium. The presence of these minerals is responsible for water hardness, and the fact that soaps lose much of their efficiency in the presence of hard water has long been recognized. Soap reacts with the dissolved magnesium salts to form insoluble, adhesive precipitates. The soap which takes part in this reaction is thus unavailable for cleaning, and the gummy deposits resist rinsing and may form a more stubborn and objectionable soil than the original dirt.

l. Object of Surface Cleaning -- The object of surface cleaning is to remove and carry away contamination without adversely affecting the part being cleaned and in the most economical manner. The apparent simplicity of this statement, however, belies the many factors which must be considered in developing an effective, engineered cleaning system. (See Table 3-1.)

Removal can be effective only if the cleaning equipment, materials, and methods are compatible with the soils to be removed, the degree of cleanliness required, the materials of construction and configuration of the part, and the mechanism by which the soils adhere to the part surface.

It should be emphasized that the removed soils must be separated and discharged in such a manner that they are not redeposited on the work surface.

m. Soils and Cleaning Methods -- The general categories of soils related to surface contamination are:

(1) oils and greases

(2) drawing and buffing compounds

(3) particulate matter of all types

(4) metal corrosion and heat-treat products

(5) human products (hair, skin, salts, etc.).

as a whole number since it is based on a logarithmic scale, represents a tenfold increase or decrease in acidity or alkalinity: pH 5 is then 10 times stronger in acid than pH 6; pH 4 is 10 times more strongly acid than pH 5 and 100 times more strongly acid than pH 6; and so forth.

Since pH is a method of stating the concentration of electrically charged groups of molecules, the most accurate method of measuring pH involves the use of a sensitive voltmeter (a pH meter) which measures the electrical potential across the charged ions and registers this in terms of pH values.

i. Buffer Activity -- The degree of acidity and alkalinity of a cleaning compound plays a part in rust and scale removal, in etching and pickling metal, in saponification, and emulsification. Buffering, the means by which a solution resists a change in the degree of acidity or alkalinity, requires very accurate pH determination. pH readings are helpful in proving comparative data on the action of a given detergent, if all other conditions have been carefully controlled.

Some of the most difficult tasks in the field of detergency, the stripping of paint from reactive metals and the removal of carbon deposits, are assigned to solvents in which ionization does not take place.

The detergent effect of a compound is not determined merely by the acid or alkaline strength of the solution. If this were the case, then raw caustics such as sodium hydroxide should be among the most efficient detergents known. Yet research and experience prove that such materials are relatively ineffective as detergents. Their potency is rapidly exhausted and, being deficient in wetting properties, they are slow to initiate cleaning action. They have no effect in conditioning hard water and are difficult to rinse.

j. Alkalinity and Acidity -- In the discussion of pH, reference was made to the distinction between the degree and the amount of alkalinity or acidity. The active alkalinity or acidity is a factor of the extent to which the detergent ionizes to yield hydrogen or hydroxyl ions. If the detergent disassociates completely during the course of the cleaning, the total amount of acid or alkali in the detergent is gradually made available for useful cleaning. Conversely, if a considerable amount of acid or alkali fails to disassociate or become active, it merely represents so much inert material or filler which plays no part in the cleaning and which is a source of rinsing difficulties.

In the selection of a detergent, the criterion of value is not the amount of acid or alkali by weight or volume which is offered, but the extent to which the acid or alkali can be made available for the removal of dirt or soil. A cleaning compound may consist entirely of alkaline substances, yet only 10 percent of this of reactive metals, such as aluminum, magnesium, copper, and zinc. Some of the most difficult problems in detergency, such as the removal of carbon from engines and stripping of paints and organic enamels, are assigned to organic solvents. The tenacious, intensely hard carbon deposits which form on engine surfaces are held together by resins formed during combustion of petroleum fuels. No available detergent has been found to exert a direct solvent action on carbon, but certain organic solvents are capable of softening and dissolving the resins which bind the carbon particles together into masses and hold them to the surface. A similar situation exists in the removal of paint where the pigment is insoluble, but where the resinous bonding agent may be softened, swelled, or dissolved by the use of suitable solvents.

h. pH and its Control -- pH is a yardstick for measuring the degree of alkalinity or acidity of water solutions. It is the measure of the energy but not of the amount of alkali or acid in solution. When table salt dissolves in water, a certain portion of it splits up into groups of electrically charged particles called ions, which are molecules of the component sodium and chlorine. Similarly, when hydrochloric acid dissolves in water it splits up, or dissociates, into groups of chlorine and hydrogen ions. When the familiar alkali caustic soda, or sodium hydroxide, dissolves in water, it yields sodium and hydroxyl ions. All acids share in common this ability to yield hydrogen (H^+) ions in water solution. All alkalis yield hydroxyl (OH^-) ions in water solution. Alkalis and acids differ greatly, however, in the number of hydroxyl or hydrogen ions they release per given weight in a given volume of water. A fluid ounce of 50-percent hydrochloric acid solution would yield a far greater number of hydrogen ions than a fluid ounce of a 50-percent solution of acetic acid. An acid which yields a great number of hydrogen ions is energetic in entering chemical unions with other substances, and is therefore described as a strong acid. The same distinction holds between strong and weak alkalis, except that the release of hydroxyl ions rather than hydrogen ions is responsible for the difference in activity in alkalis. It may be concluded, therefore, that the concentration of hydrogen and hydroxyl ions determines the relative degree of acidity or alkalinity of a water solution. To simplify expression of the values, a scale has been devised that is based on the logarithm of the reciprocal of hydrogen (or hydroxyl) ion concentration.

Values so arrived at are known as the pH values and may be arranged on a scale from 0 to 14, with 7 as the neutral point. Values above 7 indicate degrees of alkalinity; values below 7 indicate degrees of acidity. Both alkalinity and acidity become more intense as values move away from the neutral point. Thus pH 8 represents a weak alkaline solution, and a pH of 6 is a weak acidic reaction. At the other extreme, a pH of 1.5 would indicate a strongly acid solution while a pH of 13.5 would represent a strongly alkaline solution. Each increment in pH, expressed the removal of solids composed of insoluble solid particles. Carbon, clay, road film, food deposits, and paint films are among the soils removed by colloidal forces.

The mechanism of deflocculation is believed to involve the neutralization of those forces of surface tension responsible for the attraction between solid particles. Experimental data reveal that in every instance deflocculation is attendant upon a reduction of the forces of surface and interfacial tensions involved. Complete wetting of the solid is absolutely necessary to initiate deflocculation.

Colloidal forces are important not only in the direct dispersion of solid particles but in softening and swelling resinous binders, which are a factor in the adhesion of paints, enamels, and similar coatings, and in removing impacted buffing compounds.

f. Solvent Activity -- Solvents may be divided into two broad classifications: aqueous, or water base; and nonaqueous, or organic base. The solvent properties of water are utilized in cleaning to remove many salts, acids, sugar, and syrup deposits. In aqueous cleaning solutions, water also acts as the solvent medium for the detergent compounds, thereby liberating the energies which result in wetting, emulsification, saponification, and deflocculation of soil. Besides its solvent activity, water also acts as a dispersal medium for oils and particles which it will not dissolve, but which it can be made to carry in suspension. Further, it serves as a means for the application of heat energy and for applying the mechanical energy of agitation, all of which play a part in detergency.

The chief limitation of aqueous solvents as detergent agents is that they have little or no solvent effect on oils or greases. Such aqueous solvents are described as LIPOPHOBES (fat haters). Their counterpart, the nonaqueous organic solvents, are similarly described as LIPOPHILES (fat lovers).

Many solvents present hazards due to flammability and toxicity. Adequate safety precautions must be observed in their use.

g. Organic Solvents -- Another approach to the application of solvent activity in cleaning is the use of the second broad classification of solvents, the nonaqueous solvents. Derived basically from petroleum, coal, and wood, these solvents are unable to dissolve many substances which are readily soluble in water, but they do possess the ability to dissolve not only oils and greases but many resins, rubber, bitumins, paraffin, waxes, and plastics. One of the fundamental advantages of the organic solvents is that they are capable of formulations that are chemically neutral, so that they offer a method for the safe cleaning

c. Emulsification -- The forces of cohesion which hold an oily film to a surface are remarkably strong. It is almost impossible to remove an oily film completely by the shearing action of wiping or scrubbing alone. One can demonstrate this by repeatedly wiping a lard-coated frying pan with a cloth until no lard is visible, then applying the water-break test. Invariably, water will resist wetting such a surface, provided that an oil film, perhaps no more than one molecule in thickness, still persists. The surface may be considered physically clean, but it will not be chemically clean until water will not break on the surface.

As previously stated, thorough wetting results in the formation of globules of oil on the surface of the detergent film. Here the process of emulsification comes into play. If there is an emulsifying agent in the detergent, the oily globules will be detached from the surface and will be dispersed through the cleaning solution. The adhesion of the oil to the surface will be permanently disrupted. Once so scattered, the portion of the oil removed cannot be redeposited as a film.

When part of an oily film has been removed in this manner, another layer of the film is exposed to the wetting action of the detergent. Emulsifying action then comes into play again and disperses an additional portion of the oily mass. Thus, emulsification is contingent upon wetting, and further wetting is contingent upon emulsification. The combined effect of the two actions is the loosening, breaking up, and dispersion of the oily film.

d. Saponification -- Saponification is the process whereby the fatty acids in animal and vegetable oils unite chemically with certain alkaline substances to form soap. The soap so formed is quite similar to household soap in its chemical properties and behavior, if not in external appearance. The removal of fatty acid soil is one of the major problems of detergency. Many greases consist of a mixture of animal fats (such as tallow) and petroleum oils. Petroleum or mineral oils cannot be saponified and therefore must be removed through the process of wetting and emulsification. But the fatty acid components of lubricants do react with certain alkaline detergents to form water-soluble soaps.

e. Deflocculation -- Many types of soils or contaminants encountered in metal cleaning are of a solid or semisolid nature. Chemical materials which have the ability to break up a solid mass into small particles and to disperse them through a liquid medium are known as deflocculating agents. The earliest detergent known, far predating soaps and chemical detergents, is fuller's earth, a highly colloidal clay that possesses notable deflocculating powers. Colloidal activity plays a vital part in

3.1 Cleaning of Surfaces

There are seven broad classifications of processes for removal of surface contamination, any one of which may be employed as a single or multistage operation:

a. Acid cleaning

b. Alkali cleaning

c. Solvent cleaning

d. Emulsion cleaning

e. Electrolytic cleaning

f. Pickling and descaling

g. Mechanical cleaning (blast or grit, abrasive tumbling, wire brushing, and flame cleaning).

All of these methods except mechanical cleaning require electricity and/or liquids. Liquid cleaning media involve the complex phenomena of wetting activity, emulsification, deflocculation, colloidal activity and suspension, solvent power, pH values, buffer activity, alkalinity and acidity, water conditioning, sequestration and chelating, and rinsing. These factors are discussed in the following paragraphs:

a. Wetting -- For a surface to be cleaned, it must first be wetted by a cleaning solution. Wetting action brings the detergent or cleaner in closer contact with the soil and surface, ultimately penetrating the soil and removing it from the surface. While wetting activity is popularly believed to be a natural property of all liquids, in reality, liquids vary greatly in their ability to wet a surface. Water, reputedly one of the wettest of all substances, actually has less wetting power than ammonia, acetone, benzene, and most oils. But water's wetting power can be greatly increased by chemical treatments.

b. Surface Tension -- The wetting ability of any fluid can be increased by reducing its surface tension. Pure water has a much higher surface tension than most oils. When pure water is carefully poured on an oil surface, the surface tensions of the oil and water will resist one another with the result that the water is unable to spread over or wet the oil film. Instead, the water forms individual round droplets or pools with convex domes, a precise reflection of the forces of surface tensions involved in the situation. But if the surface tension of the water is reduced so that it is actually less than that of the oil film, the water will penetrate and displace the oil. The oil then forms droplets on the surface of the water film. These droplets may not be completely detached from the soiled surface, but the oily mass has been penetrated and its adhesion weakened by wetting.

SECTION 3

CONTROL OF SURFACE CONTAMINATION

Contamination of functional surfaces is a major source of the malfunction of electrical contacts and close-fitting mechanical parts. Contamination on surfaces adjacent to these areas also can contribute to product failure through sloughing or scaling of particulate matter that was not removed by the cleaning process.

There are numerous accepted techniques for detecting surface contamination, but none is applicable to all materials or to all contaminants. The few methods suitable for production use have limited application. Before methods and processes are chosen, the principles of surface cleaning should be explored in depth, because the method required to clean a surface may be a clue to the appropriate method of detecting contaminants or verifying cleanliness.

Many variables are involved in surface cleaning, such as the type of material to be cleaned, the type of contaminant, the types of cleaning methods and processes with varying equipment, as well as the consideration of further treatment to the material. There are many forms of contaminants to be removed and broad groupings of materials.

One of the potential problems is that the first or second cleaning process or solvent may cause some adverse reaction to subsequent cleaning processes or solutions. Thus the entire manufacturing process must be surveyed and each intermediate cleaning operation analyzed for its impact on the whole process.

There is no general answer to the question "when may a part be considered clean?" For example, a metal part may be wiped free of oil with a rag. It then may be visually clean, provided it is not subject to further finishing. But, if it is to be chrome-plated, any residual organic soil must be removed by electrolytic cleaning in an alkaline solution before it may be considered chemically clean. Even then it may not respond satisfactorily to electroplating due to a passive oxide film on the metal that renders the surface inert. In this instance, the part must be acid-dipped, with or without current, and with the possible use of activators calculated to remove that film. The part then may be considered metallurgically clean.

Thus, when speaking of metal cleaning, it is necessary to distinguish between <u>visually clean</u>, <u>chemically clean</u>, and <u>metallurgically clean</u>. All these terms suggest that "cleaning of metals" or the "cleanliness of metals" are relative terms; the interpretation depends on the many factors involved in a specific cleaning situation.

2.2 Performance Levels

An absolute measurement or definition of the degree of cleanliness required for a specific case is frequently impracticable or impossible. The alternative is to establish minimum product performance levels. Performance levels can be developed for:

a. Production processes

b. Appropriate levels of assembly of product

c. Controlled areas and facilities

d. Cleaning methods

e. Finished product

f. Other activities where indication of a cleanliness level is required.

When performance levels are established in lieu of cleanliness levels, they must be commensurate with the performance requirements of the product. Control methods and monitoring techniques must be employed to maintain uniform and consistent operations and to assure consistent levels of performance at all times.

2.3 Bibliography

Contamination Control Considerations for Designers and Manufacturing Engineers: Manufacturing Research Division, Sandia Corporation; SC-R-65-888; April 1965.

Contamination Control Principles: NASA SP-5045; 1967.

TABLE 2-2
(continued)

General Areas of Consideration		Characteristics for Design Considerations
	Tools, jigs, fixtures	Flaking Shedding Oils Abrasive products
	Personnel environment	Personnel contaminants Airborne contaminants
Test and inspection	Equipment gages, and fixtures	Flaking Shedding Oil Dirt Abrasion products
	Chemical tests	Dyes Residues
	Operations	Burrs Chips Plating scale Released fluids and gases Wear products Personnel contaminants
Storage	Packaging	Proper selection of: Containers Wrapping materials Cushioning materials Desiccants Barriers
	Environments	Temperature Humidity Pressure Shock Vibration
Use	Operation- Continuous Intermittent Self-destruct	Wear products Lubrication Contaminant generation Radiation
	Servicing	Introduction of, or exposure to contaminants

TABLE 2-2
(continued)

General Areas of Consideration		Characteristics for Design Considerations
Assembly processes	Product flow and assembly sequence	Migration and transfer of contaminants from: Mating assemblies Tools, jigs, fixtures Work surfaces Personnel Environment
	Rivets	Galvanic action Swaging fragments
	Nuts, bolts, screws	Shedding Burrs Chips Abrasives
	Welding, brazing, and soldering	Metal fragments Solder fragments Flux residue Fumes Oxides
	Gaskets	Flaking Shedding Lubricants
	Encapsulation, sealing	Outgassing Shedding Flaking Thermic reaction
	Cleaning	Compatibility with all materials Entrapment Gas generation Residue
	Lubricants	Excess Migration Reaction to materials
	Marking	Etch residue Flaking Shedding

TABLE 2-2
(continued)

General Areas of Consideration		Characteristics for Design Considerations
	Molding	Flash Mold release residue Mold wear products
	Forming, drawing, extrusion	Burrs Lubricants Release compounds Particles Scales
	Forging	Scale
	Machining	Blind holes Burrs and chips Sharp edges Capillary traps Coolants Cutting oils
	Chemical milling	Etch residue
	Plating	Scale Flaking Residue
	Heat treat	Scale Silica Liquids
	Cleaning	Effect on material Drying Residue Temperature effect
	Polishing	Oils Polishing compounds Chemical residue Dusts Oxides
	Tools, equipment, and personnel	Dirt Oils Wear products Personnel contaminants Airborne contaminants

(3) minimal cleaning time and action

(4) removes surface sealing compound from castings without penetrating pores

(5) degreased parts require minimum cooling time for handling.

Methyl Chloroform (1, 1, 1-trichloroethane)

(1) requires specially designed distillation equipment

(2) low vapor density necessitates higher freeboard

(3) greater solvent loss through diffusion

(4) not recommended for aluminum

(5) tendency to hydrolyze in the presence of excess water.

Trichlorotrifluoroethane

(1) low boiling point

(2) specially designed equipment needed to reduce solvent loss

(3) chemically stable under degreasing conditions

(4) generally a mild solvent action

(5) can be used discreetly with some varnishes, plastics, and rubber.

Table 3-17 lists some of the commonly encountered soils and the applicability of vapor degreasing as a means of their removal.

Vapor degreasing is a highly effective means of removing soils, particularly those in the oil and grease family. It does, however, create conditions and limitations of which the user should be aware (see Table 3-18).

f. Personnel Hazards:

(1) Toxicity -- Toxic vapors are present with degreaser solvents and adequate precautions must be taken. Excessive inhalation or absorption may cause nausea, headaches, fatigue, and loss of sense of balance. Toxic fumes may be produced if the solvent is exposed to intense light or adjacent high-temperature operations. Adequate ventilation must be used when degreaser tanks are being cleaned. A second person should always be present during the cleaning operation.

(2) Dermatitis -- Dermatitis may result from repeated or prolonged solvent contact with the skin. The skin becomes rough, red, and dry due to removal of natural skin oils. It then cracks easily and becomes susceptible to infection.

(3) Narcotic Effect -- Degreaser operators may form the habit of intermittently inhaling small amounts of solvent vapor. Proper supervision must be exercised to detect and prevent such practices. Death has been attributed to the strong narcotic power of trichloroethylene vapors in high concentrations.

TABLE 3-17

Contaminant Removal Potential of Degreasing Solvents

Easily Removed	Marginal	Not Recommended
Machining oil	Cutting compounds[a]	Inorganic fluxes
Stamping oil	Small chips[b]	Weld scale
Cutting oil	Polishing compounds[a]	Metallic oxides and salts
Grease	Buffing compounds[a]	Heat-treat scale
Wax lubricants	Organic soldering fluxes	Some carbonaceous deposits
Sealing wax	Pigmented drawing components[a]	Water soluble soils
Drawing lubricants	Shop dirt[b]	Soap-base pigmented compounds

[a] Compounds usually require agitation, spraying, or other mechanical action. The compounds may "bake on" if the part is first subjected to a vapor phase.

[b] Chips, dirt, and other insolubles can be removed if oil or grease is binding the contamination to the part. Agitation or spray enhances their removal.

TABLE 3-18

Vapor Degreaser Limitations and Cautions

Subject	Limitation or Caution	Recommendations
Acidity	Solvent may decompose, become acidic, and attack copper, titanium, aluminum, and magnesium; chlorides formed by decomposed solvents and aluminum or magnesium will further contaminate electronic components.	Periodically check solvent acidity; follow prescribed degreaser cleaning schedules; use different degreasers for aluminum or magnesium and electronic components.
Rust	Degreased ferrous parts are highly susceptible to oxidation.	Provide clean, dry atmospheres; apply rust-proofing solutions.
Heat	High solvent temperatures are deleterious to some materials such as rubber and plastic.	Check maximum safe temperatures before exposing to solvents.
	Certain polishing and buffing compounds may bake on parts at high solvent temperature.	Use spray-vapor cycle, or soak or flush with other solvents and hand brush prior to degreasing.
Chlorides	Chlorides formed by decomposed solvents and certain metals (aluminum, magnesium, beryllium) will attack some electronic components, rubbers, and plastics, as well as the metals themselves; do not use chlorinated solvents with titanium.	Check chloride effects on nonmetals; provide proper degreaser maintenance; consider separate degreasers for electronic components.
Thin-walled parts	Part temperature may increase to vapor temperature quickly so that desired cleanliness is not achieved.	Use vapor/spray/vapor cycle or cool and repeat vapor cycle.
Large parts	Part may be too large for available degreaser.	Degrease a portion of the part at a time; hand clean with solvents.
Blind holes	Depth, location or orientation may present cleaning or draining problems.	Use vapor/spray/vapor cycle; ultrasonic plus vapor; rotate part to permit drainage.
Convoluted parts and tubing	Solvents and dissolved contamination may become trapped in convolution or torturous passages.	Parts should be fixtured to rotate during degreasing and drying; a solvent pressure flush may be required.
Metal castings	Due to micro- and macro-porosity, all contaminants may not be removed from the pores; prevents proper impregnation; may subsequently weep oil.	If no insoluble contaminants present, recommend oven bake and combination of ultrasonic-vapor degreasing cleaning.
Oil-impregnated powder metal parts	Bearings and bushings may be oil-impregnated for the life of the part; degreasing will remove portions of this lubricant.	If cleaning is required, mild solvent surface wipe or brush; or completely degrease and reimpregnate.

3.4.3 Ultrasonic Cleaning

a. General -- The removal of surface soils by forces created through the implosion of vaporous bubbles (cavitation) is known as ultrasonic cleaning. This technique has been developed to the degree that it is recognized as a very effective way of removing most soils and has definite advantages over other methods.

Cleaning by ultrasonics is fast and thorough. It is, however, more complex than ordinary cleaning methods. Its cost must be expressed in relative terms for the application. For the job on which it is practical and needed, it may be the most economical means available in terms of total cost; for a misapplication, it can be an expensive luxury and less effective than other methods.

In addition to the characteristics mentioned above, a properly applied ultrasonic cleaning process offers the following advantages over other methods:

(1) less heat required

(2) parts can be cleaned without harming surface finishes

(3) assemblies can be cleaned without dismantling

(4) soils can be removed from minute cracks, pores, and indentations

(5) delicate parts and assemblies can be cleaned with a vigorous yet gentle action.

b. Basic Equipment -- An ultrasonic cleaning unit is comprised of three principal parts:

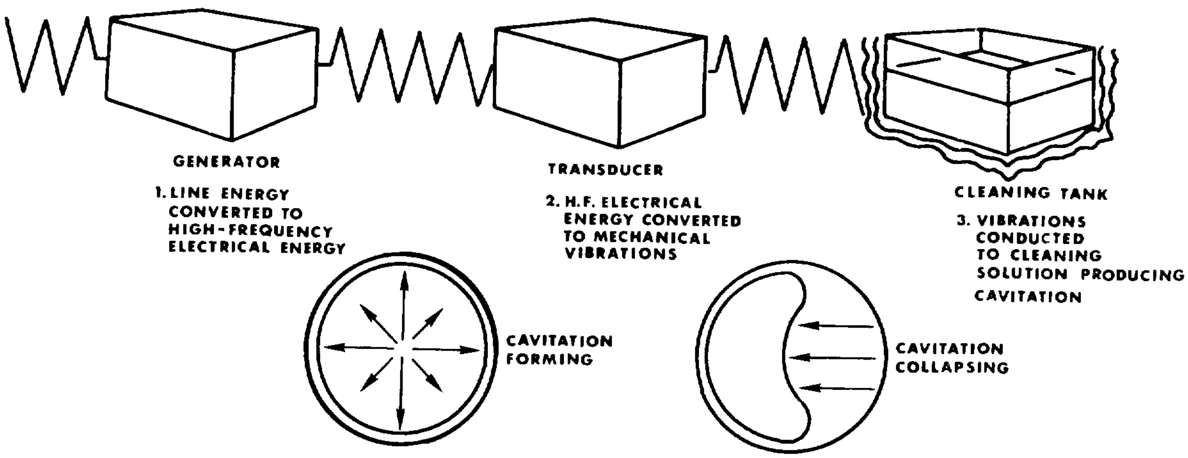
(1) a generator, which produces high-frequency electrical energy

(2) a transducer, which changes the electrical impulses into high-frequency sound waves that vibrate at a frequency in the ultrasonic range

(3) a cleaning tank, to which the transducer is attached, containing the appropriate cleaning agent.

Accessories may include work-handling devices such as baskets and hooks, frequency monitoring instrumentation, heaters, dryers, and fluid filtering and recirculating equipment. Depending on the specific application, each of these accessories may increase the overall effectiveness of an ultrasonic cleaning process.

The component parts of an ultrasonic cleaning unit are described in more detail later in this section. The relation of these components to each other and to the inducement of cavitation is shown in Figure 3-8.



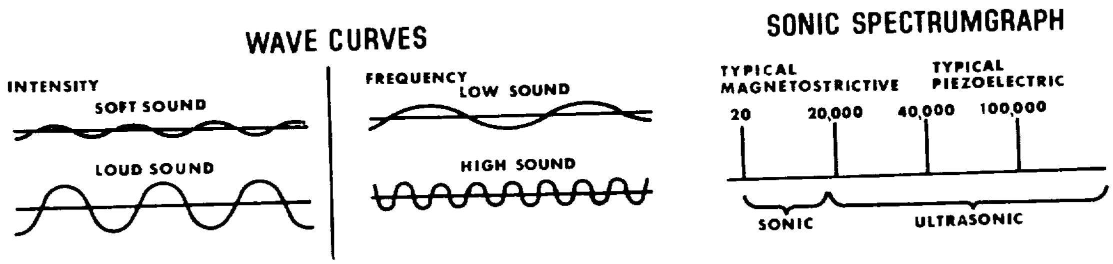
Courtesy of Turco Inc.

Figure 3-8. How ultrasonic cleaning works

c. The Nature of Sound -- Sound moves outward from its source in waves of air molecules which it alternately compresses and expands. When this vibrating air strikes an eardrum, a sound is heard.

Sound cannot travel in a vacuum. It must have a medium to carry it--a medium to vibrate in successive waves. Air is such a medium, yet there are others far better. Sound travels four times faster through water, for instance, and 15 times faster through iron.

For sound to be heard it must be of sufficient intensity, and it must be within the audible frequency range. A sound of great intensity has a wave pattern with higher crests and deeper hollows than does a weaker sound. Frequency refers to the number of sound-wave oscillations per second. The sonic frequency range is the range in which sounds are discernible. A normal human ear can respond to frequencies ranging from about 20 to 16,000 to 18,000 vibrations per second (18,000 cycles). Anything above 20,000 cycles--or 20 kilocycles--is considered to be ultrasonic. Intensity and frequency wave curves are shown in Figure 3-9. When sound passes through an elastic medium like metal, both the sound energy and the medium vibrate at the same rate. When sound passes through a liquid, the liquid ruptures or cavitates--that is, small vacuum pockets are created which almost immediately collapse. This cavitation occurs, however, only at or above the sonic intensity level of the threshold of cavitation. The rapid implosion of thousands of these cavitations provides a rapid and vigorous scrubbing action. Because cavitation can be produced essentially throughout the entire tank, it can provide a scrubbing action even in blind holes, crevices, and other normally inaccessible places.



Courtesy of Turco Inc.

Figure 3-9. Sound wave curves and spectrumgraph

d. Theory of Ultrasonic Cavitation -- Ultrasonic cleaning utilizes the scrubbing action of imploding liquid vapor bubbles to loosen and remove soil from a part. This action is enhanced by using a cleaning solution as the conducting media.

Ultrasonic energy is transmitted into the cleaning tank by the transducer on the bottom, or side, of the tank. The transducer, in vibrating at the ultrasonic frequency, is alternately moving toward and away from the liquid in the tank. When it moves toward the liquid, it produces a compression (high pressure) wave; a rarefaction (low pressure) wave is produced when it moves away from the liquid.

If the amplitude of the transducer vibration is great enough, the low-pressure ultrasonic wave will lower the pressure on the liquid in the tank below its vapor pressure, at the temperature of operation. When this occurs, thousands of minute vapor bubbles are formed in the low-pressure region. One-half cycle later, the high-pressure wave moves through this region, thereby causing the vapor to recondense to liquid, thus forming tiny partial vacuum bubbles. These implode with great force. This is ultrasonic-induced cavitation (i.e., the formation and implosion of vapor bubbles).

These cavitation bubbles provide the ultrasonic scrubbing. The more bubbles formed, the better and faster the ultrasonic cleaning. The greater the amplitude of the transducer's vibration (ultrasonic intensity), the greater the pressure differential between internal and external pressures on the cavitation bubbles, and the greater their implosive force, when they implode.

Since cavitation only occurs when the local pressure on the liquid is reduced to a value less than its vapor pressure, the amplitude of the ultrasonic waves generated by the transducer must be great enough to satisfy this condition. This minimum amount of power is referred to as the "threshold of cavitation." Obviously different liquids will have different thresholds, but the threshold must be exceeded to achieve ultrasonic cleaning. It is only that ultrasonic energy above the threshold that is contributing to the formation of cavitation bubbles and to ultrasonic cleaning.

The effectiveness of the ultrasonically induced cavitation, therefore, largely depends on the ultrasonic power intensity in the cleaning tank.

e. Physical Properties of Cleaning Liquids -- While all of the liquid physical properties will have an effect on ultrasonic cleaning, the effects of vapor pressure, surface tension, viscosity, and density are the most pronounced. Since temperature influences these properties, it also has an influence on the effectiveness of the cavitation. Examination of the individual effects of the four prime physical properties on cavitation reveals why each liquid has its own optimum temperature range for most effective cavitation. The following discussion attempts to denote differences in the effects of varying physical properties rather than to establish whether they are inherently good or bad.

As previously noted, vapor pressure definitely affects the threshold of cavitation. A low vapor pressure increases the threshold, because a greater pressure reduction is required to cause cavitation to occur than with higher vapor pressures. More of the ultrasonic energy is absorbed in getting to the threshold, with the result that there is less remaining to cause more cavitation bubbles to form. However, the individual cavitation bubbles, formed when the vapor pressure is low, implode with greater force because of the greater internal-external pressure differential. Thus cavitation bubbles formed at low vapor pressures tend to produce a more "intense" (hard) cavitation; but if the vapor pressure is low enough, so few, if any, are formed that the net cavitation is low, or even nonexistent.

With high vapor pressure, the threshold of cavitation is low, and more of the ultrasonic energy is available to cause larger numbers of cavitation bubbles to form. However, the bubbles formed at high vapor pressure implode with less force than those formed at low vapor pressure, because of the smaller internal-external pressure differential. Thus cavitation bubbles formed at high vapor pressure tend to produce a less intense (soft) cavitation.

If the vapor pressure is high enough, no implosions will occur, because the cavitation bubbles will grow so large during the low-pressure cycle that they do not have enough time to collapse during the high-pressure cycle. When this happens, the vapor bubbles increase in size with each succeeding low-pressure wave, until their buoyancy factor becomes great enough to cause them to rise to the surface of the liquid. This is known as "cold boiling" because the visual appearance of the liquid surface is identical to that of a liquid under a gentle boil, although the temperature can be well below the liquid's boiling point.

Both too high or too low a vapor pressure can adversely affect ultrasonic cavitation, with the extremes actually preventing cavitation from occurring at all. Optimum results are, therefore, obtained at moderate vapor pressures.

The fact that the forces opposing the formation of the cavitation vapor bubbles are also the ones that are involved in their collapse explains why the maximum cavitation intensity is obtained at an optimum balance between these two forces.

The effects of <u>surface tension</u> are a good example of this balance of forces. The liquid's surface tension can be considered as proportional to the elasticity of the vapor bubble wall. Thus, the greater the surface tension, the greater the force (ultrasonic energy) required to stretch the bubble wall and expand the vapor bubble to a larger size. Higher surface tension would also tend to cause the bubble to collapse faster and with more force (intensity). While high surface tension would tend to produce higher intensity cavitation, too high a surface tension can absorb so much ultrasonic energy, in so minute expansions, that the bubbles cannot grow large enough to implode with maximum intensity.

Conversely, low surface tension would not require as much force (ultrasonic energy) to expand the vapor bubble to a large size. It also would not exert much force toward causing the bubble to collapse, with a resultant low intensity (soft) implosion.

With surface tension, as with vapor pressures, it is a "middle of the road" value that gives the best results. A very high surface tension absorbs too much energy, and too low a surface tension does not provide the desired cavitation forces.

The effect of higher viscosity is one of damping and absorption of energy. Since viscosity is really a measure of shear force, higher viscosities require greater force (ultrasonic intensity) to transmit the ultrasonic wave through the liquid. Still greater intensities are required to cause cavitation in highly viscous liquids. Therefore, the lower the viscosity, the better the ultrasonic cavitation.

The effect of density is basically the common kinetic effect of lifting a given mass to a definite height and letting it fall. It takes more energy to move a heavier mass, but the impact force is greater. It does take a bit more ultrasonic energy to expand the cavitation bubbles in a higher density liquid than in a low density liquid, but the higher density liquid implodes with greater impact (i.e., F = ma). Within the density range of the common liquids used in cleaning, higher densities produce more intense cavitation.

Considering the effects these four key physical properties have on cavitation, it is easily seen that high density, low viscosity, and "middle range" surface tension and vapor pressure are the ideal conditions for the most intense cavitation. Lower temperatures give higher density (desirable), higher viscosity (less desirable), higher surface tension (less desirable), and lower vapor pressure (less desirable). Higher temperatures, near the liquid's boiling point, produce lower density (less desirable), lower viscosity (desirable), lower surface tension (less desirable), and higher vapor pressure (less desirable). (See Figure 3-10.)

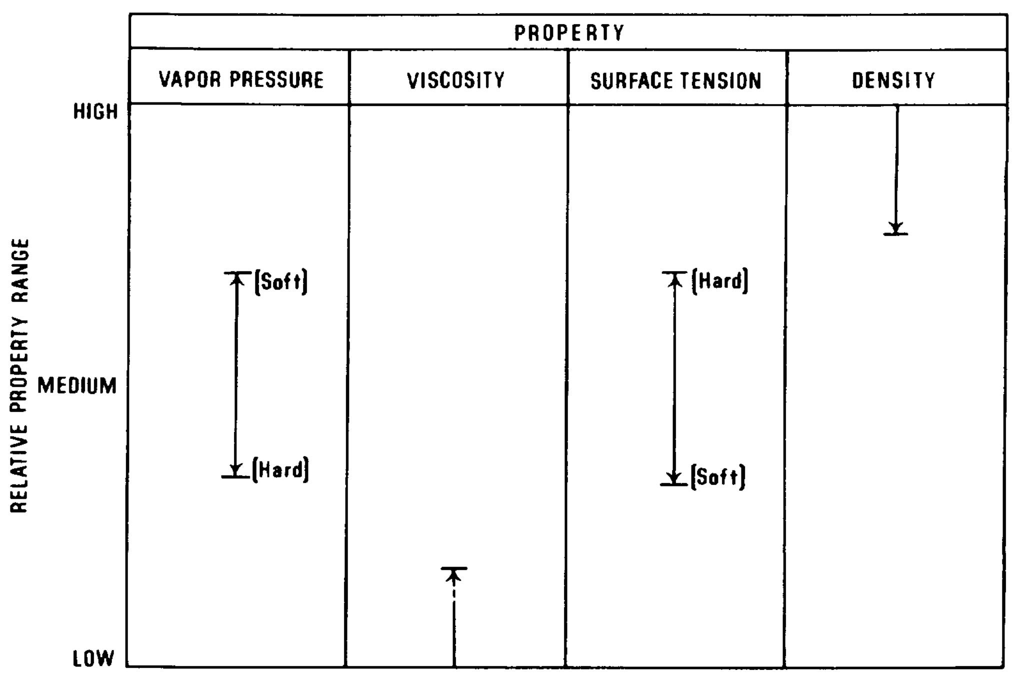


Figure 3-10. Relative ranges of liquid physical properties for maximum cavitation intensity

Due to temperature effects on these four physical properties, the best (most intense) cavitation will be considerably below the liquid's boiling point, but not so low as to get into the adverse regions of too low vapor pressure and too high a surface tension. Different liquids will have different temperatures at which the cavitation intensity will be the most intense, because of differences in physical properties and their rates of change with temperature. Thus, the cavitation intensity will be less either above or below this ideal temperature.

For ethyl alcohol this ideal temperature, at a pressure of one atmosphere, is in the range of 65° to 70°F for maximum cavitation intensity (Figure 3-11). Water cavitates best in the range of 140° to 160°F, with a peak about 150°F. As temperature decreases from the ideal, cavitation intensity falls off gradually, but the rate of decrease in intensity with decreasing temperature will vary with different liquids.

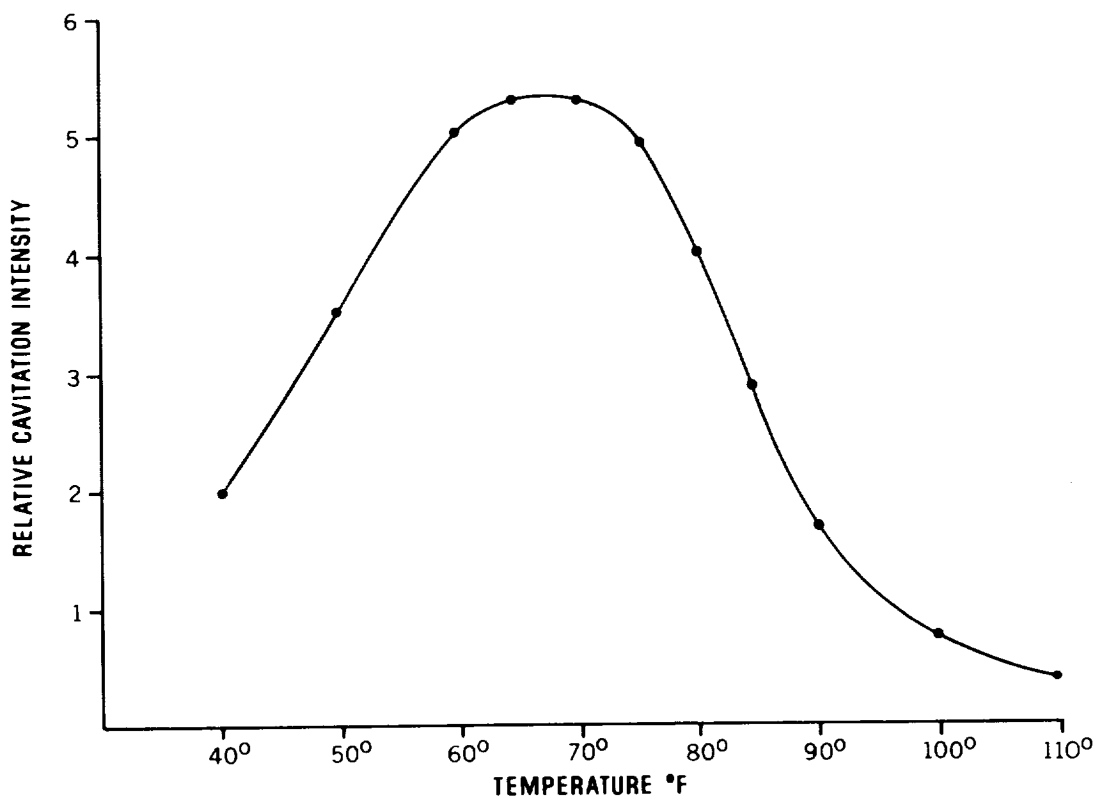


Figure 3-11. Relative cavitation intensity versus temperature for ethanol

As temperature increases above the ideal, cavitation intensity falls off quite rapidly. Again the rate of change is different for each liquid. Water at 180°F only cavitates with about two-thirds the intensity that it has at 150°F, while ethyl alcohol falls to about 50 to 75 percent of its peak intensity at 85°F, and to about 20 percent of peak at 100°F. Because ethyl alcohol cavitates with a softer (less violent) cavitation, even at its peak intensity, decreases in its intensity can markedly influence cleaning results. It is true that increasing temperature usually improves the chemical action of the cleaning solutions. In some cases, the improvement in chemical action with increased temperature is great enough to actually result in better cleaning, even at 10° to 30°F above the ideal temperature for best cavitation. However, further increases in temperature result in such a marked decrease in cavitation intensity that the overall cleaning also decreases, despite the better "chemical action" at the higher temperature. The point at which this occurs may be considered the "maximum effective operating temperature" because higher temperatures prevent gaining any appreciable benefits from ultrasonic cavitational activity. For water, this temperature is about 180°F; for ethyl alcohol and methylene chloride, it is about 85°F, while other liquids have their own characteristic "max temperatures." Cavitation effectively ceases when a cleaning fluid reaches its boiling point.

Since the addition of cleaning chemicals to a liquid affects the physical properties of surface tension, viscosity, and density, these materials also affect the ideal temperature as well as the maximum temperature of the liquids to which they are added. Each cleaning mixture, therefore, has a temperature range in which it functions best as an ultrasonic cleaning material. Failure to use it in this range can result in failure to achieve satisfactory cleaning.

It is important that the ultrasonic cleaning equipment be able to produce the power intensity required for the particular cleaning job. It is also important that it have sufficient total power output to handle the parts load it is expected to clean. It is equally important, however, that the proper cleaning chemical be used within its best cleaning temperature range, if the ultrasonic equipment is to be capable of producing the proper cleaning results.

f. Operation -- A complete ultrasonic cleaning system is complex. It is necessary to consider many factors to achieve maximum cleaning effectiveness. Some of these factors, along with their relation to effective ultrasonic cleaning, are shown in Table 3-19.

TABLE 3-19

Considerations for Effective Ultrasonic Cleaning

Factors of Operation	Remarks
Cleaning solution	Select the proper cleaning solution for the cleaning job to be done. Liquid level should be adequate to prevent damage to ultrasonic unit.
Degassing	Any solution should be degassed before use. Complete degassing time depends on the properties of the solution, especially temperature, tank depth, power intensity, and type of pulse. Shallower tanks, higher solution temperatures, and higher power intensity with a pulsed wave allows faster degassing. Soft or deionized water is more easily degassed than hard water. Partial degassing (80-85%) should take place in about 5 minutes. Complete degassing should occur after about 30 minutes, but the time may vary depending on the above factors. Heating the solvent to within 3° to 5°F of its boiling point will also accomplish degassing.
Immersing parts	Slow immersion and removal of parts from the cleaning solution will prevent the introduction of air and the bouncing back of reflective ultrasonic waves to the transducer and generator. Parts should be withdrawn from the tank while the cleaner is operating. If the ultrasonic tank emits sharp screeching sounds, the parts are being introduced too fast and the generator is put under undue stress.
Parts loading	Load parts in the ultrasonic cleaning tank such that neither the parts nor the parts basket is on the tank bottom. Heavy parts (high mass) should each be exposed to direct ultrasonic waves. If they are stacked on top of each other, the top parts may not get cleaned. The sum of the parts cross-sectional area should not exceed 75% of the tank cross-sectional area. For the most effective cleaning, total parts weight should not exceed .35 lb/kW of generator power, even though a slightly higher weight-to-kW ratio can be accommodated. Elastomers and nonrigid plastics will absorb ultrasonic energy and will produce a shadowing effect; insulated parts may have to be specifically oriented.
Container design	Incorrect basket design or a basket having too high a mass can greatly reduce the effectiveness of the best ultrasonic cleaning system. Any material more tightly woven than 50 mesh screen acts as a solid sheet, while slightly larger openings scatter the ultrasonic waves; openings larger than 1/4 in. act as open material. Hooks, racks, and beakers can also be used to support parts.
Parts positioning	Parts positioning, important in most cleaning operations, is doubly important in ultrasonic cleaning. If possible, critical areas to be cleaned should face the transducer, but racked parts should be positioned vertically rather than being stacked one on top of the other. Care must be taken so that air is not trapped in blind holes, thereby preventing liquid contact with all surfaces. Parts should be covered by at least 3/4 in. of cleaning fluid and, if possible, should be positioned at the correct depth to take advantage of the higher intensity at the antinode of the ultrasonic wave.
Noises	Audible noise of two types may be produced; a buzzing or hissing noise is caused by the shock waves produced by cavitation bubbles; screeches or squeals resulting from "beat notes" should be avoided. Beat notes can be caused by (1) moving parts in the tank too fast, (2) too violent agitation of the liquid, (3) resonant bubbles, or (4) two or more nonsynchronized generators. Introduction of a parts basket or parts into the liquid will usually eliminate beat notes from these causes. Beat notes may also be caused by cleaning chemicals which do not form clear solutions or by excessive accumulations of greasy soils which are not completely soluble in the solution used; if this occurs, use a different solution or change the solution more frequently.
Filtering	In precision cleaning, particulate matter must be removed from the cleaning fluid. This may be done with a continuously recirculating filtration system simultaneously with ultrasonic cleaning. The rate of flow through a filter system should be determined through experimentation with each cleaner. A depth filter should precede the absolute filter for maximum practical effectiveness. The rate of flow is generally not over 1 to 3% of the tank volume per minute, as too high a rate will prevent the cavitation process by creating turbulence and may produce screeching sounds.

g. Cleaning Applications and Soils Removed -- Allied with some of the advantages of ultrasonic cleaning, mentioned previously, are the variety of applications and the effectiveness in removing a wide range of soils displayed by the ultrasonic cleaning process. The following information presents typical examples of cleaning solutions used, types of soils removed, and the types of parts that can be cleaned by ultrasonic methods.

Although many variations of basic cleaning solutions are commercially available under their trade names, the following are often used:

Water	Other aqueous solutions
Deionized water	Ethanol
Water + surfactants	Chlorinated hydrocarbon solvents
Water + mild acid	Fluorinated hydrocarbon solvents
Water + mild alkali	Water + solvents

Examples of the types of soils removed by ultrasonic cleaning are:

Small particulate matter	Graphite and drawing compounds
Light oils and grease	Microbial contaminants
Buffing and polishing compounds	Fingerprints
Resists	Heat scale
Solder flux	Abrasive dust
Coolant residue	

A representative list of parts that can be ultrasonically cleaned are:

Bearings	Filters
Precision gears	Semiconductors
Printed circuit boards	Microfilm
Lenses	Electrical and electronic components
Timing mechanisms	
Hydraulic system components	Surgical instruments

The preceding listings are not intended to be inclusive, but they indicate the variety of cleaning situations in which ultrasonic cleaning can be applied successfully. No attempt is made to recommend the solvent, procedures, or detailed ultrasonic process for a specific cleaning situation, since all of the variables discussed in this section should be considered.

Ultrasonic cleaners, if properly used, offer the user the advantages of fast and effective cleaning. The full capability of an ultrasonic cleaner cannot be realized, however, unless care is taken in the selection of the proper cleaning solution.

Properly formulated compounds and cleaning solutions perform the following important functions in an ultrasonic cleaning tank:

(1) lower interfacial tension, providing better contact of the cleaning solution with the soiled parts

(2) lower surface tension, decreasing energy losses from cavitation heating

(3) penetrate the soil rapidly, thus allowing the ultrasonic scrubbing action to take maximum effect at the point of contact between soil and part

(4) react chemically with the soil, which, in some instances, decreases removal and dispersion time

(5) aid in dispersing the soil and prevent soil redeposition when the part is removed from the ultrasonic cleaning tank.

h. Generator -- The function of the ultrasonic generator is to convert line voltage (110-220-440 volts) to high-frequency electrical energy.

Generators are of two basic types: electronic and motor alternator. Electronic generators may be either tube or solid state. These are available in half wave, full wave, and continuous unmodulated generators.

One method for comparing generators can be expressed in terms of the ratio of peak power output to average power output. On this basis, three types of generators are compared in Table 3-20.

TABLE 3-20

Comparison of Generator Outputs

Type of Generator	Peak Power Output to Average Power Output
Half wave	25%
Full wave	50%
Continuous	70.7%

Another common method of describing ultrasonic generators is by the average power intensity delivered to the cleaning tank. This may be expressed in three ways: watts per gallon of solution, watts per square inch of transducer face, and watts per square inch of tank cross section. The derivation and use of these methods of measurement are described in Table 3-21. Proper tuning of an ultrasonic generator is very important. The purpose of tuning the generator is to keep the cleaning tank in acoustic resonance.

TABLE 3-21

Methods of Calculating Generator Output

Method	Derivation	Application
Watts per gallon	Divide average power of generator by the volume of the solution	Indication of needed tank heating and cooling requirements
Watts per square inch of transducer face	Divide average power of generator by the transducer area (in.^{2})	Indication of power intensity when using side-mounted, immersible or partial area transducers
Watts per square inch of tank cross section	Divide average power of generator by tank cross-sectional area (in.^{2})	Furnishes average power intensity (W/in.^{2}) for complete tank, normal rating factor for standard bottom-mounted transducers

Acoustic resonance is affected by solution density, chamber dimensions (liquid level), acoustic impedance (degree of parts loading), and temperature (effect on sound velocity). A change in any of these factors affects the resonance of the cleaning tank and thereby the level of cavitational intensity of which the unit is capable of producing. The effect of nonresonance is shown in Table 3-22.

TABLE 3-22

Resonance Versus Nonresonance at Full Power

Resonant Condition	Relative Cavitational Intensity
In resonance	10
Off resonance, 110 cycles	8
Off resonance, 225 cycles	4
Off resonance, 450 cycles	1

The three standard types of tuning methods for ultrasonic generators are: manual, fixed, and automatic. The discriminating features of these tuning methods are described in Table 3-23.

TABLE 3-23

Ultrasonic Generator Tuning Methods

Tuning Method	Characteristics
Manual	Variable tuning within the available tuning range; accurate tuning depends on operator knowledge of the changes and effects of each variable factor; must be retuned for optimum cleaning efficiency as the factors change.
Fixed	Tuning is fixed for one set of operating conditions; may be satisfactory for high production if all variables remain constant; less flexibility.
Automatic	Adjusts automatically to changing factors; eliminates chance for operator error; more complex mechanism; assures optimum cavitation intensity.

i. Transducers -- The ultrasonic transducer converts high frequency electrical energy into mechanical vibrations. The transducer provides the "driving" force through the tank structure (or plate for submersible transducers) which causes ultrasonic cavitation. It is, therefore, sometimes called the heart of an ultrasonic cleaning system.

There are basically two types of transducers, electrostrictive (piezoelectric) and magnetostrictive. There are significant differences between the two types as well as among variations within the same type. The information in Table 3-24 attempts to point out these technical differences. Photographs showing structural differences are shown in Figure 3-12.

j. Electronic Components -- Electronic components such as transistors, diodes, semiconductors, and assembled circuit boards have been damaged as a result of being cleaned in ultrasonic cleaners. Since it is also well established that such components can be successfully cleaned by this method, it is important to observe the rules set forth in Table 3-25.

k. Ultrasonic Cleaning Efficiency -- Many techniques are available for measuring or deriving a measure of ultrasonic cleaning efficiency. The selection of any specific technique usually depends on the parameter to be measured.

Many of the factors mentioned earlier in this section affect the efficiency of an ultrasonic cleaning unit. In review, these are:

(1) generator type and frequency output

(2) transducer type and average power output

(3) temperature and properties of cleaning solution

(4) parts loading and positioning

(5) impedance and acoustical matching.

TABLE 3-24

Types and Characteristics of Ultrasonic Transducers

Type	Material and Construction	Characteristics
Electrostrictive	Artificially polarized ceramic wafer of barium titanate	High voltage, low amperage; operates in the 40 kc and higher range; subject to thermal and mechanical shock damage and to depolarization from heat; spaced in array fashion.
Electrostrictive (alloy)	Artificially polarized ceramic wafer of lead-zirconate-titanate alloy	Essentially same as above, but can withstand higher operating temperature and power inputs.
Modified electrostrictive	Ceramic wafers of the above types sandwiched between two blocks of metal	Effect of metal blocks dampens output to the subharmonic 20 to 25-kc range, although some are available which operate at 40 kc.
Magnetostrictive	Usually consists of stacks of sheet nickel clamped together to form a core	Resistant to thermal and mechanical shock; relatively high mass and weight; operates in the 20 to 25-kc range; lower electrical-to-mechanical efficiency than electrostrictive.
Modified magnetostrictive	Honeycomb-type construction of laminated nickel	Shock resistant; low mass and weight, higher mechanical-to-acoustical efficiency; operates in 20 to 25-kc range; high transducer-to-radiating surface ratio; uniform and high power intensity.

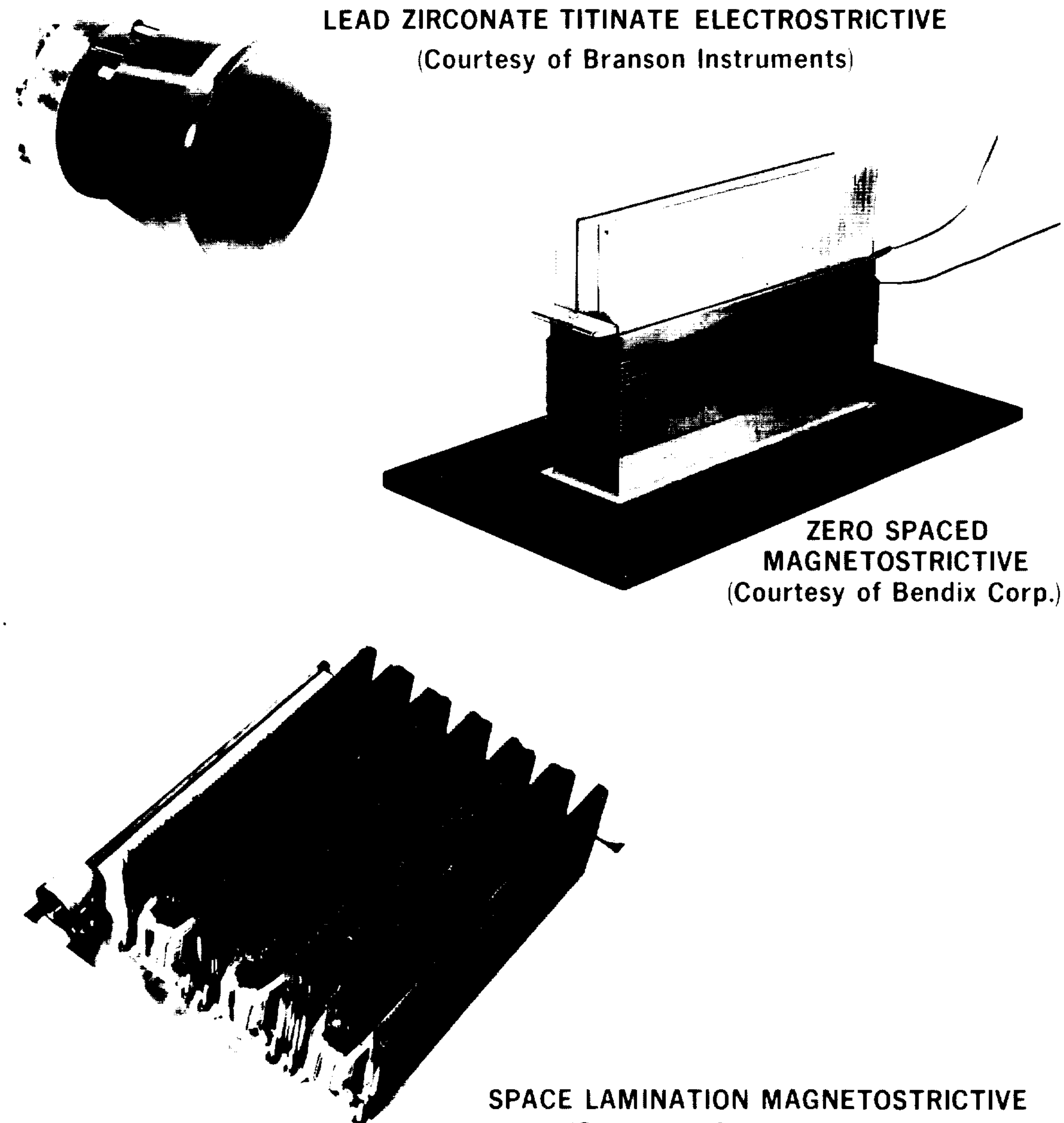


Figure 3-12. Ultrasonic transducers

TABLE 3-25

Considerations for Ultrasonically Cleaning Electronic Components

Parameter	Resolution
Physical structure	Components manufactured by some producers are not structurally sound enough to withstand ultrasonic cleaning. The alternatives are to clean them in another manner or use other components that can be cleaned ultrasonically.
Power intensity	Any delicate component has an upper limit for power intensity with reference to time. A maximum of 5 $W/in.^2$ at a nominal 20 kc is suggested.
Power uniformity	Cleaners with a nonuniform power intensity can expose components to higher intensities than those recommended for safe operation on electronic components.
Mass of load	Electronic components, particularly circuit boards, should be ultrasonically cleaned in racked loads, not as individual parts.
Dwell time	The time the parts are exposed (immersed) to ultrasonic cavitation should be very closely controlled; 5 to 15 seconds is usually sufficient, depending on all other considerations.
Cleaning solution	The type of solution has a direct effect on the type (hard or soft) of cavitation produced. Solutions with those qualities producing soft cavitation, i.e., high-vapor pressure and low-surface tension, should be used.

Some of the methods advanced for measuring the performance of ultrasonic cleaning units are in reality a measure of cavitation intensity. Cleaning efficiency and cavitation intensity are not synonymous, but a close relationship between the two exits, since the principal ingredient in ultrasonic cleaning is cavitation intensity. Other methods attempt to measure different parameters to which some correlation to cleaning efficiency can be proven or logically assumed.

Some of the more widely accepted methods of evaluation are included in Table 3-26. A reasonably complete list of known and proposed methods is shown in Table 3-27.

TABLE 3-26

Ultrasonic Cleaning Monitoring Methods

Measuring Device or Method	Parameter Measured	Principle of Operation	Characteristics or Limitations
Foil erosion	Cavitational intensity	Cavitational action erodes immersed foil strip	Effects more apparent in water than solvents; indicates standing wave patterns or modification thereof. All variable factors--location, height, temper, thickness, solution, solution temperature, power input, etc.--must remain constant for comparison tests. Simple to perform; fair reliability; can be performed in either tank or beaker. No meaningful standards have been developed; evaluation is dependent on visual comparison and individual interpretation. Does not provide continuous readings; usually limited to testing before or after a cleaning operation.
Bead or steel ball bounce	Vibration of the container and subsequent movement of beads or ball	Ultrasonic energy in the solution produces a vibration of the test tube, which in turn imparts a bouncing motion to the beads or ball	Simple to perform. Difficult to interpret results accurately. Performed in a test tube or Erlenmeyer flask. Used by some companies, but not generally considered as an effective means of evaluation.
Heat rise	Temperature of the solution in the cleaning tank	The release of ultrasonic energy causes a temperature rise in the solution, which is plotted against time	May be used for day-to-day evaluation of the same unit. Plotted curve of temperature rise versus time should approximate a straight line. Heat transfer by conduction or convection into or out of tank must be minimized. Degraded transducers can generate more heat which is transferred to the solution and gives false readings. Not a true measure of cavitation.
Cavitation intensity meters	Cavitational intensity (actually measures the by-products such as spectral lines and white noise)	Probe picks up white noise frequencies and filters out fundamental frequency	Advantages of this method include a direct readout, and ease and quickness of testing. Each manufacturer has different units of measurement. Some units do not have range switches; may be frequency- and temperature-sensitive.
Chlorine release (chemical oxidation)	Correlation between vaporous cavitation and chlorine liberation	Cavitation energy present releases chloride from an aqueous carbon tetrachloride solution	Strongly frequency- and temperature-dependent. Correlated with other methods only in the 20 to 40-kHz range. Amount of liberated chlorine is determined by optical density measurements with a spectrophotometer. Results usually expressed in milligrams per unit of time. Limited to low temperatures.
Dispersion probe	Amount of soil removed	Scrubbing action removes known soil deposited on ground or etched glass probe	Effectiveness of cleaning determined by light transmission or reflectometer tests before and after cleaning. Difficult to deposit a uniform amount of graphite for each test.
Standard soil test piece	Amount of soil removed	Standard soil is baked on a test piece, then removed by cleaning for a standard time	Various soils, temperatures, and baking times may be selected by user. Offers some quantitative data if soil application is uniform. Somewhat complex and time-consuming.
Standard test piece	Surface cleanliness of test piece	Amount of soil removed is indicative of cleaning effectiveness.	Most nearly simulates actual conditions. Extent and type of initial soil should be reasonably constant. Surface cleanliness after cleaning is usually evaluated by water break, coefficient of friction, electrical conductivity or oxide film tests.
Transducer amplitude	Amplitude of motion of transducer radiating surface at a given spot	Based on the assumption that there is some correlation between amplitude of vibration and cavitational intensity	Measures transducer double amplitude; uses probe (resonant accelerometer) to pick up amplitude. With proper attachments, it can furnish readout in microns. Can be used to continuously monitor or spot check. Results vary with fluid used.

TABLE 3-27

Proposed Methods of Evaluating Ultrasonic Treatment Systems*

Probe Methods

- Acoustic pressure-sensitive
- Velocity sensitive
- Acoustic absorption
- Displacement sensitive
- Feel
- Bouncing beads
- Calorimetric expansion
- Noise sensitive
- Rayleigh disc
- Radiometer
- Hot-wire microphone
- Thermocouple in lossy matrix
- Acoustic fluxmeter
- Signal to noise
- Total noise
- Subharmonic measurement
- Semiconductor thermo-resistors
- Photoelastic
- Emulsion probe
- Electrolytic probe

Erosion

- Foil (heavy)
- Soil removal
- Strips or rods
- Foil (light)
- Dispersion

Sonochemical

- Chlorine release
- Bromine release
- Sonoluminescence
- Chemical oxidation
- H_2O_2 formation
- Depolymerization

Surface Cleanliness Tests of Cleaned Sample

- Water break
- Coefficient of friction
- Surface electrical conductivity
- Adhesion of evaporated or sprayed on metal film to nonmetallic surface
- Thermally induced oxide film (400°C) (metals)
- Plating effectiveness (metal)
- Standard soil
  - Radioactive tracer
  - Reflectometer
  - Light transmission
  - Chemical tracer
  - Fluorescent dye
  - Chemical dye

Calorimetric

- Substitution
- Thermal isolation
- Constant flow
- Acoustic dilatometer

Other

- Visual
- Complex transducer electrical impedance
- Reaction of radiation pressure
- Fountain or surface distortion
- Volume flow rate
- Heat transfer
- Complex mechanical impedance
- Light scattering
- Volume change
- Change in conductance
- Attenuation by scattering
- Printing
- Biological cell breakage

*Courtesy of D. Ensminger, Battelle Memorial Institute, Columbus, Ohio.

It should be emphasized that the ultimate test for ultrasonic cleaning efficiency is whether the desired cleaning function is achieved. Stated another way, are the parts cleaned to the desired cleanliness level, and in the shortest reasonable time? Other factors such as damage to parts and effective service life should also be considered.

It is suggested that the criteria for an ideal monitoring method should include at least the following points:

(1) adaptable to both beaker and tank cleaning

(2) simple to administer in terms of time and procedure

(3) not dependent on human judgment

(4) repeatable and reliable

(5) meaningful in terms of cleaning effectiveness

(6) numerical readout in standard units.

1. Hazards -- Prolonged contact of any part of the body with ultrasonically activated equipment or solutions could cause bone or tissue damage. However, the body part would usually be removed from the solution by reflex action, due to heat and pain, before any damage could occur. Sound frequencies in the subultrasonic (15 to 18 kc) range may be painful but not necessarily harmful to the ear. It is recommended that prolonged exposure to these frequencies be avoided, although it should be noted that these frequencies are below the ultrasonic range. Any ultrasonic cleaning system should be properly grounded to prevent electric shock.

3.4.4 Drying Methods

The subject of drying is closely associated with parts cleaning. Several methods are discussed in this section because each may have application depending on the cleaning situation encountered. It should be pointed out, however, that the environment during cleaning and drying, and prior to the next operation, must be sufficiently clean to maintain the level of cleanliness achieved by the cleaning operation. If superclean surfaces are required, cleaning and drying operations should be performed in a clean bench or clean room environment.

Drying methods are generally divided into the following categories:

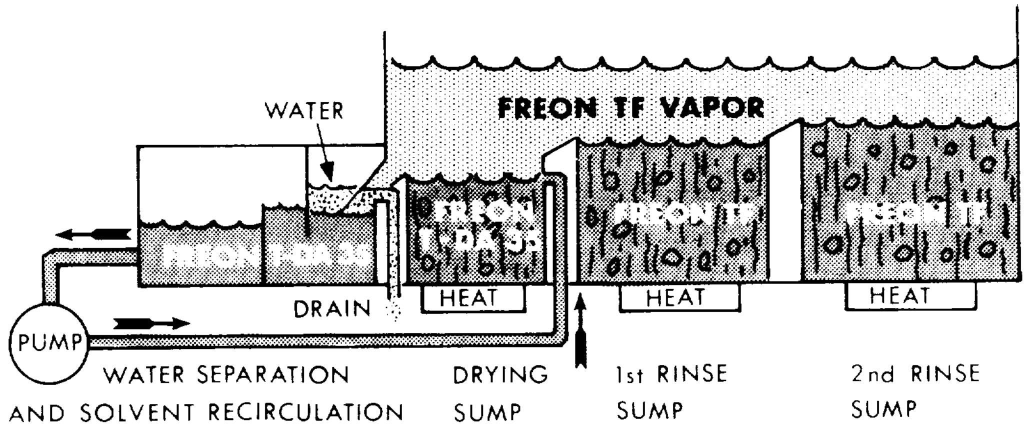
Mechanical	Chemical	Thermal
Wiping	Alcohol	Ovens
Air blowoff	Acetone	Infrared
Dry nitrogen blowoff	Freon T-WD 602	Light banks
Sonic	Freon T-DA 35	Vacuum ovens
	Trisec	

More detailed information on these methods is given in Table 3-28.

TABLE 3-28

Characteristics of Drying Methods

Method	Drying Action	Remarks
Wiping	Absorption by wiping material	Use lint-free cloth; usually gross or predry operation; not preferred.
Air blowoff	Physical force displaces cleaning solution; air movement aids evaporation	Air-supply line must have filter, water trap, and regulator; use care in not agitating other contamination in immediate environment.
Dry nitrogen blowoff	Same as above	Essentially same as above; final drying for precision work.
Sonic	Moisture concentration gradient near part surface modified by air agitation by sound waves; extraction	Not too widely used with metals; can be used with heat-sensitive parts or where high-velocity air would cause damage.
Alcohol and acetone	May combine cleaning and drying; water absorption; rapid evaporation	Effective in some cleaning operations; requires caution in handling; highly flammable.
Freon T-WD 602	Water emulsification Vapor evaporation	Dries traces of residual water from surfaces, small holes, and cracks; used in ultrasonic or vapor-degreasing equipment.
Freon T-DA 35	Water displacement	Removes large or small quantities of water from metals, plastics, and material combinations; used in conjunction with Freon TF in specially designed, vapor degreasers; parts must be properly oriented in the solution; see Figure 3-13.
Trisec	Water displacement	Combination of chlorinated solvent and a cationic surfactant; requires modified vapor degreaser.
Ovens	Evaporation by heat	Should be recirculating, indirect gas-fired or electrically heated, with high-volume static exhaust; not applicable for heat-sensitive materials.
Infrared and heat light bank	Evaporation by heat	Not normally used if contamination control is a factor; usually a conveyorized operation.



Courtesy of E. I. du Pont de Nemours and Company

Figure 3-13. Freon T-DA 35 drying system

a. Displacement Drying -- Due to the relative newness of water displacement drying systems, some of the distinguishing characteristics of this type system are listed below:

(1) relatively low operating temperature - $<120^\circ F$

(2) drying cycle can be completed in 4 to 7 minutes

(3) nonflammable, low hazard materials

(4) Freon T-DA 35 and water are immiscible; therefore, the water is separated and discharged without contaminating the solvent

(5) spot-free and contamination-free surfaces are obtainable.

3.5 Cleaning Agents

In a contamination control program, the selection and proper use of an effective cleaning agent are usually a vital consideration. The solvent selected not only must be compatible with the cleaning method and materials of construction but also must be capable of removing the soils encountered to the desired degree and within practical time limits.

It is often necessary to incorporate the use of different cleaning agents to remove different types of soils or to set up a progressive cleaning operation such that the final stage produces the needed cleanliness level. The planning effort for a cleaning operation must consider many factors, the most important of which is the solvent chemistry. This, as well as properties and characteristics of the cleaning agents, is discussed in succeeding portions of this section.

The list of commercially available cleaning agents is too long to include in this handbook. They are, therefore, treated in various types of groups. The composition of these groups may be determined by chemical composition, soils removed, affect on materials, or function. Individual cleaning agents are also considered as points of reference to the more commonly used formulations or when they are indicative of a group.

NOTICE

With reference to cleaning agents, no attempt is made to include all trade name products. The variety and number of these products caused by special formulations and different trade names for the same agent preclude such a listing.

Some products are named as an indication of the type or class of cleaning agent being described. The use of any trade or company name does not constitute an endorsement of that product, nor should the absence of any name be construed as a lack of confidence in any manufacturer, supplier, or product.

3.5.1 Kauri-Butanol Values

Solvent power or solvency can be measured in many ways. In order to be comparative, however, a known or established standard must be used. For purposes of standardization, the solvent industry, as well as some users, have adopted the kauri-butanol system.

Solvent power as expressed by kauri-butanol values is the amount of solvent which when added to a standard kauri gum solution in butanol produces a definite turbidity as compared to the amount of benzene used in a similar titration. As determined, it is the number of milliliters of solvent that must be added to 20 grams of standard kauri solution at 25°C to produce sufficient precipitate of the gum, so that a printed sheet of paper (10-point century type) will appear blurred and illegible when viewed through the flask containing the solution. In most cases, 100 milliliters of benzene will produce the desired condition. The kauri-butanol number for benzene, therefore, is 100.0, which is the arbitrarily accepted standard.

Kauri-butanol values serve as a guide or index of relative solvency power, using an arbitrary standard. In this respect, and in the absence of a more precise method, these values serve a purpose. It must be emphasized, however, that kauri-butanol values may not be indicative of the most effective solvent in a specific cleaning situation. Other factors such as temperature, time, cleaning method, and materials must also be considered.

Kauri-butanol values for some representative and commonly used solvents are listed in Table 3-29.

TABLE 3-29

Kauri-Butanol Values for Representative Solvents

Solvent	Kauri-Butanol Value
Trichlorotrifluoroethane	31
Stoddard solvent	34
Mineral spirits	39
Perchloroethylene	90
1, 1, 1-Trichloroethane	124
Trichloroethylene	130
Methylene chloride	136
Chloroform	208

3.5.2 Properties and Characteristics

As pointed out previously, the properties and characteristics of a cleaning agent are of prime importance because they affect or have a distinct bearing on all other cleaning considerations. Disregard for these factors can result in incomplete cleaning, damage to materials, improper application of cleaning methods, and higher costs. The properties of cleaning solvents are shown in Table 3-30.

The physical properties of solvents are fairly well known to those working in the cleaning field. In addition, these properties are readily available from chemistry handbooks, cleaning reference books, and charts prepared by the major chemical producers.

The fact that these data are available does not assure, however, that full significance of the data is known and understood by people responsible for specifying cleaning operations. Solvent candidates for a specific cleaning job should be analyzed in detail to determine the most effective solvent for a specific application. Table 3-31 describes the significance of some of the physical properties important to cleaning.

3.5.3 Effects on Materials of Construction

No cleaning system can be considered optimum unless the effect of the cleaning agent on the material of construction is considered. This consideration will not enhance cleaning effectiveness, but it is vital to preserving the finishes and integrity of the materials being cleaned.

While many agents are inhibited to prevent material damage, some tend to lose their inhibitive qualities or to combine with other elements to form acids after prolonged use. This factor should be taken into account when developing operating controls and maintenance programs.

Cleaning agent manufacturers should be consulted for information on the effects of their products on specific materials to be cleaned. It is further suggested that tests be run under actual operating conditions to determine what effect, if any, the cleaning agent will have on the material.

The effects of some common cleaning solvents on selected materials are shown in Table 3-32.

3.5.4 Effects on Soils

Cleaning agents by their nature have been found or are designed to be effective in removing certain types of soils from surfaces. The degree of effectiveness depends to a large extent on the reaction of the soil to the solvent chemistry. Other factors such as the cleaning method, exposure time, and solution temperature will also directly affect cleaning efficiency.

Table 3-33 presents a comparison of cleaning agent effectiveness in removing certain types of soils. This information is general in nature because of the many variables involved in any given cleaning situation.

3.5.5 Cleaning Agents and Compatible Cleaning Methods

Throughout this handbook, the need for a thoroughly engineered cleaning system for each cleaning situation is stressed. The systems approach which considers all factors is most important. A list of cleaning agents (pp. 76-92) provides information which may be used as a guide in selecting the proper cleaning agent for a particular cleaning method. Other factors such as time, agitation, soil, and materials of construction must be considered before a proper cleaning agent can be selected.

TABLE 3-30

Solvent Properties Comparison Chart

Aromatics	Formula	Molecular Weight	Pounds per Gal at 68°F	Boiling Range (°F)	Freezing Point (°F)	Evaporation Rate (Carbon Tetra-chloride = 100)	Coefficient of Expansion per °F
BENZOL (Benzene)	C_6H_6	78.11	7.32	172-176	41.9	95	0.00069
TOLUOL (Toluene)	$C_6H_5(CH_3)$	92.13	7.20	228-232	139.0	58	0.00061
XYLOL (Xylene) (mixed isomers)	$C_6H_4(CH_3)_2$	106.16	7.17	261-318	-	45	0.00055
m-CRESOL	C_7H_7OH	108.13	8.66	396-406	51.6-53.6	-	-
Alphatic Petroleum							
n-PENTANE	$CH_3(CH_2)_3CH_3$	72.15	5.22	91-106	-201.5	271	0.00079
TEXTILE SPIRITS	-	-	5.75 60°F	145-175	-	-	0.00072
n-HEXANE	$CH_3(CH_2)_4CH_3$	86.17	5.51	151-160	-139.5	139	0.00075
n-HEPTANE	$CH_3(CH_2)_5CH_3$	100.20	5.71	196-214	-131.1	97	0.00068
VM & P NAPHTHA	-	-	6.29 60°F	236-292	<-50	37	0.00061
HI-FLASH VM & P NAPHTHA	-	-	6.33 60°F	240-320	<-50	8	0.00061
MINERAL SPIRITS NO. 10	-	-	6.51 60°F	307-385	-92	-	0.00054
STODDARD SOLVENT	-	-	6.47 60°F	310-388	<-45	61	0.00061
MINERAL SPIRITS	-	-	6.58 60°F	314-390	<-50	-	0.00050
VARSOL-1	-	-	6.58 60°F	322-386	-	-	-
ODORLESS MINERAL SPIRITS	-	-	6.31 60°F	352-398	-	-	0.00061
KEROSENE	-	-	6.77 60°F	374-503	-	-	0.00050
INK SOLVENT	-	-	6.79 60°F	512-610	-	-	-

NOTES: *In oxygen.
**Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.
***Estimated.

TABLE 3-30
(continued)

Surface Tension at 68°F (dynes/cm)	Solubility % by Weight at 68°F: In Water	Solubility % by Weight at 68°F: Of Water	Flash Point (Tag closed cup) (°F)	Flammable Limits % by Volume in Air: Lower	Flammable Limits % by Volume in Air: Upper	Toxicity TLV in PPM	Specific Heat Liquid at 68°F (Btu/(lb)(°F)	Latent Heat at B. P. (Btu/lb)	Kauri-Butanol Value (cc)
28.9	0.09	0.06	12	1.4	8.0	25**	$0.42^{59°F}$	170	105-150
28.4	0.05	0.04	40	1.3	7.0	200**	0.41	156	94-105
28.9	$0.02^{59°F}$	0.02	80	1.1	7.0	100**	$0.40^{86°F}$	147	94
37.4	2.35	-	86	$1.1^{302°F}$	-	5**	0.55	181	-
-	$0.04^{60°F}$	-	< -40	1.4	8.0	1000**	0.54	154	26.0
22.5	-	-	-20	1.2	6.8	-	-	-	32.8
18.4	$0.014^{60°F}$	-	-7	1.2	6.9	500**	0.54	145	32.5
-	$0.005^{60°F}$	< 0.02	25	1.2	6.7	500**	0.53	138	35.5
25.4	-	-	48	$0.9^{212°F}$	$6.0^{212°F}$	500	-	-	38.5
25.8	-	-	57	1.2	6.0	500	-	-	36.4
27.6	-	-	105	1.1	6.0	500	-	-	34.0
27.6	—	-	105	1.1	6.0	500**	-	-	34.0
27.8	-	-	110	1.1	6.0	-	-	-	39.0
-	-	-	113	1.1	6.0	-	-	-	38.0
27.0	-	-	128	1.1	6.1	-	-	-	26.2
30.0	-	0.06	145	1.2	6.0	-	-	-	29.5
-	-	-	250	-	-	-	-	-	22.1

† Very slightly soluble.
- Data not available.
†† Open cup.

TABLE 3-30
(continued)

Alcohols	Formula	Molecular Weight	Pounds per Gal at 68° F	Boiling Range (°F)	Freezing Point (°F)	Evaporation Rate (Carbon Tetra-chloride = 100)	Coefficient of Expansion per °F
METHANOL	CH_3OH	32.04	6.61	147-151	-144.0	50	0.00066
ETHANOL, ANHYDROUS	CH_2H_5OH	46.07	6.59	171-176	-174.1	-	0.00063
ETHANOL, 95%	C_2H_5OH	46.07	6.76	166-175	-198.4	37	0.00062
ISOPROPANOL, 99%	$(CH_3)_2CHOH$	60.09	6.55	179-181	-126.0	34	0.00062
n-PROPANOL	C_3H_7OH	60.09	6.74	207-208	-196.6	34	0.00053
ISOBUTYL ALCOHOL	$(CH_3)_2C_2H_3OH$	74.12	6.72	225-232	-162.4	16	0.00053
n-BUTYL ALCOHOL	C_4H_9OH	74.12	6.75	239-245	-129.6	13	0.00052
sec-BUTYL ALCOHOL	$C_2H_5CHOHCH_3$	74.12	6.73	208-214	-174.5	21	0.00055
AMYL ALCOHOL (mixed isomers)	$C_5H_{11}OH$	88.15	6.76	230-293	-	7	0.00052
CYCLOHEXANOL	$C_6H_{11}OH$	100.16	7.91	320-324	77.2	2	0.00043
n-HEXANOL	$C_6H_{13}OH$	102.17	6.83	307-320	-60.9	-	0.00050
Esters							
METHYL ACETATE	$CH_3CO_2CH_3$	74.08	7.58	127-136	-145.6	118	0.00074
ETHYL ACETATE (99%)	$CH_3CO_2C_2H_5$	88.10	7.50	169-174	-118.5	-	0.00077
ISOBUTYL ACETATE	$CH_3CO_2CH_2CH(CH_3)_2$	116.16	7.24	220-246	-146.0	45	0.00066
n-BUTYL ACETATE	$CH_3CO_2C_4H_9$	116.16	7.28	244-262	-100.3	34	0.00067
sec-BUTYL ACETATE	$CH_3CO_2CH(CH_3)C_2H_5$	116.16	7.27	219-239	-146.0	50	0.00067
METHYL CELLOSOLVE ACETATE	$CH_3CO_2C_2H_4OCH_3$	118.13	8.37	279-306	-85.2	12	0.00061
AMYL ACETATE (mixed isomers)	$CH_3CO_2C_5H_{11}$	130.18	7.21	259-311	-	23	0.00061
n-BUTYL PROPIONATE	$C_2H_5CO_2C_4H_9$	130.18	7.27	255-340	-129.2	16	0.00060
CELLOSOLVE ACETATE	$CH_3CO_2C_2H_4OC_2H_5$	132.16	8.10	302-320	-79.1	8	0.00062

NOTES: *In oxygen.
**Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.
***Estimated.

Reprinted with permission from the Solvent Properties Comparison Chart, E. I. Du Pont De Nemours & Company, Copyright 1966.

TABLE 3-30
(continued)

Surface Tension at 68°F (dynes/cm)	Solubility % by Weight at 68°F		Flash Point (Tag closed cup) (°F)	Flammable Limits % by Volume in Air		Toxicity TLV in PPM	Specific Heat Liquid at 68°F (Btu/(lb)(°F))	Latent Heat at B. P. (Btu/lb)	Kauri-Butanol Value (cc)
	In Water	Of Water		Lower	Upper				
22.6	∞	∞	54	6.0	36.5	200**	0.60	473	-
22.3	∞	∞	57	3.3	19.0	1000**	$0.58^{77^\circ F}$	361	-
22.8	∞	∞	57	3.3	19.0	1000**	$0.62^{73^\circ F}$	-	-
21.7	∞	∞	56	2.5	5.2	400**	0.60	287	-
23.8	∞	∞	59	2.5	13.5	--	$0.57^{77^\circ F}$	296	-
22.8	10	15	64	1.7	-	100	0.58	249	-
24.6	7.7	20.1	84	1.7	18.0	100**	0.56	254	-
23.5	20.1	36.3	76	-	-	100	0.67	242	-
23.6	$2.4^{59^\circ F}$	11.0	111	1.2	-	100**	-	-	-
$34.2^{61^\circ F}$	3.6	20.0	154	-	-	50**	$0.42^{58^\circ F}$	195	-
24.5	0.58	7.2	145	-	-	100	$0.50^{75^\circ F}$	209	-
24.6	24.5	8.2	15	4.1	13.9	200**	$0.47^{59^\circ F}$	177	-
23.9	8.7	3.3	24	2.2	11.5	400**	0.46	158	-
23.3	0.75	1.1	64	-	-	200	0.46	133	-
$27.6^{81^\circ F}$	0.68	1.2	72	1.7	15.0	150**	$0.51^{75^\circ F}$	133	-
-	$0.74^{77^\circ F}$	$2.1^{77^\circ F}$	66	1.7	-	200	$0.46^{75^\circ F}$	140	-
31.8	∞	∞	132	1.7	8.2	25**	$0.50^{86^\circ F}$	158	-
	1.0	1.7	77	1.1		100**	0.49	123	-
-	0.15	0.8	90	-	-	-	0.46	129	-
$31.8^{77^\circ F}$	22.9	6.5	124	6.5	1.7	100**	0.49	145	-

† Very slightly soluble.
- Data not available.
†† Open cup.

TABLE 3-30
(continued)

Chlorinated Hydrocarbons	Formula	Molecular Weight	Pounds per Gal at 68°F	Boiling Range (°F)	Freezing Point (°F)	Evaporation Rate (Carbon Tetra-chloride = 100)	Coefficient of Expansion per °F
n-PROPYL CHLORIDE	$CH_3(CH_2)_2Cl$	78.54	7.43	113-117	-189.0	187	0.00080
ISOPROPYL CHLORIDE	$CH_3CHClCH_3$	78.54	7.17	94-104	-178.6	-	0.00088
METHYLENE CHLORIDE	CH_2Cl_2	84.94	11.07	102-106	-142.1	147	0.00076
DICHLOROETHYLENE (1, 1)	$CH_2{:}CCl_2$	96.95	$10.43^{59°F}$	99	-188.5	105	-
ETHYLENE DICHLORIDE	CH_2ClCH_2Cl	98.97	10.45	180-183	-31.5	79	0.00065
MONOCHLOROBENZENE	C_6H_5Cl	112.56	9.23	266-273	-49.4	32	0.00051
PROPYLENE DICHLORIDE	$CH_2ClCHClCH_3$	112.99	9.65	204-208	<-94.0	71	0.00064
CHLOROFORM	$CHCl_3$	119.39	12.43	142	-82.3	118	0.00071
TRICHLOROETHYLENE	$ClCH{:}CCl_2$	131.40	12.22	188-198	-123.5	84	0.00065
TRICHLOROETHANE (1, 1, 2)	$CH_2ClCHCl_2$	133.42	12.04	230-239	-34.1	21	-
1, 1, 1, TRICHLOROETHANE (Methyl Chloroform)	CH_3CCl_3	133.42	11.03	162-190	-58.0	139	-
ORTHO DICHLOROBENZENE	$C_6H_4Cl_2$	147.01	10.89	351-361	1.0	7	0.00046
CARBON TETRACHLORIDE	CCl_4	153.84	13.30	171-172	-9.3	100	0.00069
PERCHLOROETHYLENE	$CCl_2{:}CCl_2$	165.85	13.55	250-254	-8.2	39	0.00057
TETRACHLOROETHANE (symmetrical)	$CHCl_2CHCl_2$	167.86	13.35	295-297	-32.8	14	0.00057
TETRACHLOROETHANE (unsymmetrical)	CH_2ClCCl_3	167.86	13.25	264-267	-91.7	-	-
TRICHLOROBENZENE (mixed isomers)	$C_6H_3Cl_3$	181.46	$12.15^{77°F}$	415-423	62.6	-	0.00048

NOTES: *In oxygen.
**Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.
***Estimated.

TABLE 3-30
(continued)

Surface Tension at 68°F (dynes/cm)	Solubility % by Weight at 68°F		Flash Point (Tag closed cup) (°F)	Flammable Limits % by Volume in Air		Toxicity TLV in PPM	Specific Heat Liquid at 68°F (Btu/(lb)(°F))	Latent Heat at B. P. (Btu/lb)	Kauri-Butanol Value (cc)
	In Water	Of Water		Lower	Upper				
-	0.27	-	0	2.6	10.5	-	-	-	-
-	0.31	-	-26	2.8	10.7	-	-	-	-
28.2	1.38	0.15	None	15.5*	66.4*	500**	0.28	141	136
-	-	-	57	5.6	13.0	-	-	-	-
32.2	0.90	0.15	56	6.2	15.9	50**	0.31	139	-
33.2	0.05	$0.04^{77°F}$	85	$1.8^{212°F}$	$9.6^{302°F}$	75**	0.32	140	-
$31.4^{77°F}$	0.27	0.06	59	3.4	14.5	75**	$0.33^{77°F}$	123	102
27.2	0.82	0.07	None	Nonflammable		50**	0.23	106	208
$32.0^{77°F}$	0.11	0.02	None	12	86	100**	0.23	103	130
33.6	0.44	0.05	None	Nonflammable		100	0.27	109	-
$25.5^{74°F}$	$< 0.10^{77°F}$		None	-	-	350**	-	-	-
-	$0.01^{77°F}$	-	151	-	-	50**	0.27	117	-
26.8	0.08	0.01	None	Nonflammable		10**	0.21	84	114
32.3	0.02	0.01	None	Nonflammable		100**	0.21	90	90
36.0	$0.29^{77°F}$	$0.13^{77°F}$	None	Nonflammable		5**	0.27	99	-
-	0.02	-	-	-	-	-	-	-	-
$38.9^{77°F}$	$< 0.01^{77°F}$	$0.22^{77°F}$	212	-	-	—	0.20	105	-

† Very slightly soluble.
- Data not available.
†† Open cup.

TABLE 3-30
(continued)

Ethers and Ether Alcohols	Formula	Molecular Weight	Pounds per Gal at 68°F	Boiling Range (°F)	Freezing Point (°F)	Evaporation Rate (Carbon Tetra-chloride = 100)	Coefficient of Expansion per °F
ETHYL ETHER	$(C_2H_5)_2O$	74.12	5.96	93-95	-177.3	263	0.00092
METHYL CELLOSOLVE‡	$CH_3O(CH_2)_2OH$	76.09	8.03	250-259	-121.2	12	0.00052
CELLOSOLVE‡	$C_2H_5O(CH_2)_2OH$	90.12	7.74	270-279	-94.0	9	0.00054
ISOPROPYL ETHER	$(CH_3)_2CHOCH(CH_3)_2$	102.17	6.04	145-158	-121.9	187	0.00083
n-BUTYL CELLOSOLVE‡	$C_4H_9OC_2H_4OH$	118.17	7.51	331-343	< -40.0	3	0.00048
DIETHYL CELLOSOLVE‡	$(C_2H_5OCH_2)_2$	118.17	7.02	243-264	-101.2	-	0.00067
METHYL CARBITOL	$CH_3OC_2H_4OC_2H_4OH$	120.15	8.56	370-388	-	-	0.00048
n-BUTYL ETHER	$(C_4H_9)_2O$	130.22	6.40	279-289	-139.4	-	-
CARBITOL‡	$C_2H_5O(CH_2)_2O(CH_2)_2OH$	134.17	8.55	365-401	< -104.8	-	0.00046
BUTYL CARBITOL‡	$C_4H_9O(CH_2)_2O(CH_2)_2OH$	162.22	7.95	428-455	-90.6	-	0.00048
Terpenes							
DIPENTENE (d1)	$C_{10}H_{16}$	136.23	7.10	342-374	-139.9	-	0.00048
TURPENTINE STEAM DISTILL	$C_{10}H_{16}$	136.23	7.13	311-343	-58.0	< 1	0.00049

NOTES: *In oxygen.
**Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.
***Estimated.
‡Cellosolve and Carbitol are trademarks of Union Carbide Corp.

TABLE 3-30
(continued)

Surface Tension at 68°F (dynes/cm)	Solubility % by Weight at 68°F		Flash Point (Tag closed cup) (°F)	Flammable Limits % by Volume in Air		Toxicity TLV in PPM	Specific Heat Liquid at 68°F (Btu/(lb)(°F))	Latent Heat at B. P. (Btu/lb)	Kauri-Butanol Value (cc)
	In Water	Of Water		Lower	Upper				
17.0	6.9	1.3	-20	1.9	36.5	400**	0.55	151	-
$35.0^{77°F}$	∞	∞	107	$2.5^{257°F}$	$19.8^{284°F}$	25**	0.53	243	-
$32.0^{77°F}$	∞	∞	104	2.6	15.7	200**	0.56	234	-
32.0	0.90	0.57	-18	1.4	21.0	500**	0.51	123	-
$31.5^{77°F}$	∞	∞	141	$1.1^{338°F}$	$10.6^{356°F}$	50**	0.58	171	-
-	21.0	3.4	95††	-	-	120	-	178	-
$41.3^{77°F}$	∞	∞	200††	-	-	-	$0.51^{73°F}$	163	-
22.9	0.3	0.19	77	-	-	-	$0.49^{59°F}$	122	-
$35.5^{77°F}$	∞	∞	201	-	-	-	0.55	173	-
$33.6^{77°F}$	∞	∞	172	-	-	-	0.55	111	-
$27.5^{92°F}$	VSS	-	109	-	-	-	-	125	62
$26.1^{91°F}$	VSS	-	95	0.8	-	100**	-	123	55

†Very slightly soluble.
-Data not available.
††Open cup.

TABLE 3-30
(continued)

Ketones	Formula	Molecular Weight	Pounds per Gal at 68°F	Boiling Range (°F)	Freezing Point (°F)	Evaporation Rate (Carbon Tetra-chloride = 100)
ACETONE	CH_3COCH_3	58.08	6.58	132-134	-138.6	139
METHYL ETHYL KETONE	$CH_3COC_2H_5$	72.10	6.71	174-177	-123.5	97
CYCLOHEXANONE	$(CH_2)_5CO$	98.14	7.88	266-343	-49.0	12
METHYL ISOBUTYL KETONE	$(CH_3)_2CHCH_2COCH_3$	100.16	6.68	234-244	-120.5	47
METHYL n-BUTYL KETONE	$CH_3COC_4H_9$	100.16	6.83	237-279	-70.4	32
METHYL CYCLOHEXANONE (mixed isomers)	$(CH_3)C_6H_9{:}O$	112.17	7.67	237-343	-	7
METHYL n-AMYL KETONE	$CH_3(CH_2)_4COCH_3$	114.18	6.81	297-309	-31.9	15
DIACETONE	$(CH_3)_2C(OH)CH_2COCH_3$	116.16	7.82	266-356	-65.2	4
Fluorinated Hydrocarbons						
Dichloromonofluoromethane (Fluorocarbon 21)	$CHCl_2F$	102.9	-	48.1	-211	-
Tetrachlorodifluoroethane (Fluorocarbon 112)	CCl_2FCCl_2F	203.9	13.64 $^{84°F}$	199	+79	35
Trichloromonofluoromethane (Fluorocarbon 11)	CCl_3F	137.4	12.42	75	-168	225
Trichlorotrifluoroethane (Fluorocarbon 113)	CCl_2FCClF_2	187.4	13.16	117.6	-31	170

FLUORINATED BLENDS AND AZEOTROPES

Many variations of fluorinated solvents are available in the form of blends and azeotropes. These are composed primarily of fluorocarbon 113 and small amounts of additives such as isopropyl alcohol, methylene chloride, acetone, chloroform, or detergents. These may be purchased from many sources as proprietary blends for specific cleaning applications.

NOTES: *In oxygen.
**Threshold limit values for 1965, American Conference of Governmental Industrial Hygienists.
***Estimated.

Reprinted with permission from the Solvent Properties Comparison Chart, E. I. DuPont De Nemours & Company, Copyright 1966.

TABLE 3-30
(continued)

Coefficient of Expansion per °F	Surface Tension at 68°F (dynes/cm)	Solubility % by Weight at 68°F		Flash Point (Tag closed cup) (°F)	Flammable Limits % by Volume in Air		Toxicity TLV in PPM	Specific Heat Liquid at 68°F (Btu/(lb)(°F)	Latent Heat at B. P. (Btu/lb)	Kauri-Butanol Value (cc)
		In Water	Of Water		Lower	Upper				
0.00080	23.7	∞	∞	0	2.6	12.8	1000**	0.51	224	-
0.00076	24.6	26.8	11.8	28	1.8	11.5	250**	0.53	191	-
0.00051	-	2.3	8.0	145	1.1	-	50**	0.49	-	-
0.00063	22.7	2.0	1.8	64	1.4	7.5	100**	0.50	157	-
0.00055	25.5	$3.4^{77°F}$	$3.7^{77°F}$	73	1.2	8.0	100**	0.55	148	-
0.00047	-	0.2	3.0	118	-	-	100**	$0.44^{59°F}$	-	-
0.00057	-	0.4	1.5	120††	-	-	100	-	149	-
0.00055	29.8	∞	∞	48	-	-	50**	$0.50^{59°F}$	200	-
	$18^{77°F}$	-	-	None	-	-	1000	0.26	104	76
	$23.0^{86°F}$	-	-	None	-	-	500	0.22 (est.)	67	70
	19.6	-	-	None	-	-	1000	0.21	78.3	60
	19.6	-	-	None	-	-	1000	0.22	63.12	31

†Very slightly soluble.
-Data not available.
††Open cup.

ACETONE

(Dimethyl/Ketone, Methylacetyl, Propanone - 2) $CH_3CO.CH_3$

EFFECTIVITY

Vinyl resins; natural and synthetic lacquers, varnishes, fats, waxes, oil, grease, crude rubber, shellac, asphalt, bitumens.

CLEANING METHODS

Cold applications; dip, slosh, brush, static ultrasonic tank.

ADVANTAGES

1. Very high solvent power.
2. Miscible with water, alcohols, ethers, animal and vegetable oils, hydrocarbons, fatty acid esters, and most organic solvents.
3. Low corrosive level to metals, except in aged or recovered acetone which may develop acidity and cause discoloration and slight corrosion with copper.

DISADVANTAGES

1. Not good for removing particulate matter.
2. Incompatible with many construction materials.
3. See Hazards.
4. Not applicable for automation.

HAZARDS

Toxicity

TLV is 1000 ppm. For moderate exposure near this level, acetone vapor is quite irritating to the eyes, nose, and throat. Some workers may become accustomed to the vapor and suffer little discomfort, although it has a slight narcotic action and may produce a headache and slight nausea. Some persons may detect some of these symptoms at levels around 400 ppm.

Flammability

Highly flammable, and vapor forms explosive mixture with air.

RECLAMATION

Suffers some deterioration and develops a tendency towards acidity.

HANDLING AND STORAGE

The Cellulose Solutions Regulations govern the use of acetone in lacquers, etc. There may be local ordinances or codes affecting the storage and use. Special regulations are in force covering transport via road, rail, and water.

SPECIFICATIONS

ASTM D329-33.

BENZENE

(Benzol, Phenylhydride, Coal Naphtha) C_6H_6

EFFECTIVITY

Cellulose ethers (methyl, ethyl, butyl, benzyl); cellulose esters (cellulose dinaphthenate, dilaurate, dipalmitate, distearate, dinitrolaurate, dinitropalmitate, and diacetyllaurate), fats, waxes, gums, and rubbers.

CLEANING METHODS

Cold cleaning; dip, slosh, brush, and static ultrasonic tank. All facilities should be ventilated.

ADVANTAGES

1. Practically no corrosive effect in purer grades.

DISADVANTAGES

1. See Hazards.
2. Poor compatibility with materials of construction.
3. Not applicable for automation.

HAZARDS

Toxicity

Vapor is critically toxic, and may be absorbed not only by inhalation but directly through the skin as well. Exposure may produce an initial period of exhilaration, followed by headache, vertigo, and nausea. Lengthy exposure to high concentrations may lead to spasms and death.

There is strong evidence that benzene is a chronic poison, and that it may accumulate in the system as the result of regular exposure to rather low concentrations, leading to harmful effects. Chronic poisoning may produce anaemia and a tendency to leukemia. TLV is 25 ppm.

Flammability

Highly flammable, and over a wide range the vapor forms explosive mixtures with air.

RECLAMATION

Hazardous, not recommended.

HANDLING AND STORAGE

Due to high volatility and explosive character when mixed with air, this solvent should be in tightly closed containers and away from light. Mild steel containers are adequate.

SPECIFICATIONS

On 90-percent benzene: ASTM D361-36.

CARBON TETRACHLORIDE

(Tetrachloromethane) CCl_4

EFFECTIVITY

Fixed, mineral and essential oils; fats; greases; waxes; gums; camphor; metallic resinates; bitumens; asphalt; unvulcanized rubber; some cellulose ethers; resins such as coumarone, dammar, ester gum, elemi, guaiac, mastic, sandarac, rosin, and alkyd and vinyl resins.

CLEANING METHODS

Cold cleaning employing fluids from dip to fully automated systems.

ADVANTAGES

1. Miscible with acetic anhydride, ethyl alcohol, ethyl ether, naphtha, benzene, and halogenated hydrocarbons.
2. Good solvent.

DISADVANTAGES

1. Inhibitors and stabilizers are a problem.
2. Restrictive safety precautions require continual monitoring.
3. Very effective ventilation must be provided.
4. Carbon tetrachloride will form phosgene, chlorine, or hydrochloric acid gases if it decomposes.
5. See Hazards.

HAZARDS

Toxicity

Strongly narcotic, even at moderate concentrations, and rapidly induces unconsciousness and death.

Symptoms of exposure are usually indicated by moderate burning of the eyes and skin, narcosis, vertigo, and headache.

Injury to the liver, kidneys, and other organs may result from a single short exposure at high concentration, or from prolonged or frequent inhalation of low vapor concentrations.

Some individuals may have a definite sensitivity to carbon tetrachloride vapors which makes it intolerable to them. TLV is 10 ppm.

Flammability

Although nonflammable in either the liquid or vapor condition, contact with either fire or water at high temperatures produces phosgene, chlorine, and hydrochloric acid gases.

HANDLING AND STORAGE

Exposure to light or moisture will cause release of traces of hydrochloric acid which is highly corrosive, so regular checking of stocks should be maintained to deter acidity.

CHLOROFORM

(Trichloromethane) $CHCl_3$

EFFECTIVITY

1. Fats; fixed, mineral, and essential oils; waxes, alkaloids, resins, and tars.
2. A latent solvent for cellulose derivatives.
3. When combined with a lower alcohol or ester, ethyl alcohol, or ethyl acetate, the mixture becomes a solvent for many cellulose esters and ethers.

CLEANING METHODS

Cold cleaning from dip to fully automated, providing adequate exhaust of vapors.

ADVANTAGES

1. A powerful solvent.
2. Soluble in ethyl alcohol and ethyl ether.
3. Miscible with all halogenated hydrocarbons.

DISADVANTAGES

1. Inhibitors and stabilizers are a constant problem.
2. A sophisticated ventilation system is mandatory.
3. Only slightly soluble in water.
4. With age, chloroform tends to oxidize to phosgene and hydrochloric acid.
5. Strong degreasing action of $CHCl_3$ on the skin will cause burns and cracking, with possible secondary infection and dermatitis.

HAZARDS

Toxicity

1. TLV is 50 ppm.
2. At moderate concentrations, chloroform vapor is inclined to induce gradual fatigue and headaches.
3. At high concentrations the narcotic effects are marked, producing dizziness and vomiting.
4. At still higher concentration levels, an anesthesia is very rapid. Continued exposure at these levels may be fatal; repeated inhalation of even the lower concentrations may result in damage to liver, kidneys, and other body organs.

FLAMMABILITY

Although nonflammable, contact with either fire or water at elevated temperatures may produce highly toxic fumes of hydrochloric acid, phosgene, and like mixtures.

RECLAMATION

Not usually attempted.

HANDLING AND STORAGE

1. Pure dry chloroform is noncorrosive to most common metals, although there is evidence that in this state it will slowly attack copper.
2. If the chloroform is exposed to air, moisture, or light, it very rapidly becomes acid. It should always be stored in a cool, dry, dark area.
3. There are local and regional regulations in many localities which govern the storage, handling, and shipment of this product.

DICHLOROMETHANE

(Methyl Dichloride, Methylene Chloride) CH_2Cl_2

EFFECTIVITY

Fats; oil; waxes; rubbers; alkaloids, bitumens, and cellulose triacetate.

CLEANING METHODS

All equipment techniques applicable, from hand dip to fully automated systems, with appropriate ventilation provided.

ADVANTAGES

1. Miscible in any proportion with alcohol, ether, and chloroform.
2. Good solvent.

DISADVANTAGES

1. Not compatible with many normal materials of construction.
2. Only slightly soluble in water.
3. Highly volatile and poisonous.

HAZARDS

Toxicity

1. TLV is 500 ppm.
2. Narcotic and toxic, and at high concentrations is a rapid anesthetic.
3. Irritating to eyes, nose, and throat.
4. Injury to the liver, kidneys, and other organs may result from protracted or repetitive exposure to even low concentrations of vapors.
5. Inadequate ventilation may promote any of the above conditions.

Flammability

Nonflammable.

RECLAMATION

Normal recovery methods are applicable, including distillation. Care should be exercised to ascertain that old, recovered, or redistilled dichloromethane does not contain free acids or halogens.

HANDLING AND STORAGE

Moisture free, pure solvent is not corrosive to iron, mild steel, or aluminum; copper is not recommended.

ETHYL ALCOHOL

(Ethanol, Grain Alcohol, Alcohol) CH_3CH_2OH

EFFECTIVITY

Oil; gums; natural resins, and such synthetic resins as ethylcellulose, polyvinyl acetate, and polyvinyl butyral. A latent solvent for nitrocellulose.

CLEANING METHODS

As a cold solvent, is applicable for dip, slosh, brush, and cold static processes. Not appropriate for automation.

ADVANTAGES

1. Relatively low level of toxicity.
2. Not dangerous to use.
3. Miscible with water.
4. Noncorrosive to metals.

DISADVANTAGES

1. See Hazards.
2. Strict governmental control for pure alcohol, but not for denatured alcohol.
3. Difficult to dry without leaving residue.

HAZARDS

Toxicity

1. Although not hazardous for industrial use, continuous or long term exposure to high concentrations of vapors will irritate the respiratory tract, produce headaches, dizziness, even nausea. Most per sons develop a tolerance readily.
2. TLV is 1000 ppm.

Flammability

Very flammable.

RECLAMATION

Hazardous.

HANDLING AND STORAGE

Must be handled or stored in airtight containers, and away from open flames.

SPECIFICATIONS

MIL-A 6091B(ASG), January 12, 1962.

FLUOROTRICHLOROMETHANE

CCl_3F

EFFECTIVITY

Miscible in all proportions with acetone, benzene, carbon tetrachloride, chloroform, ether, ethyl alcohol, hexane, kerosene, methyl alcohol, and mineral oils.

CLEANING METHODS

From simple immersion to slushing, closed loop slushing, cold dip or closed chamber vapor degreasing techniques.

ADVANTAGES

1. Will not attack metals or other construction materials.
2. With agitation or when solvent flow technique is employed, it exhibits a washing action that adds to effectiveness as a cleaning agent.
3. Steel, cast iron, brass, copper, tin, lead, zinc, aluminum, and magnesium may be safely cleaned under normal conditions.

DISADVANTAGES

1. The hands should be protected by neoprene gloves.
2. When water is present, long exposure of solvent at elevated temperatures may have some adverse effect on zinc, magnesium, aluminum, or steel.

HAZARDS

Toxicity

1. Neoprene gloves should be worn to prevent drying of the skin, or absorption through the skin.
2. Should not be taken internally.

3. TLV is 1000 ppm.

Flammability

Underwriter Laboratories reports (MH-2375) that fluorotrichloromethane (Freon-MF, or -11) is incapable of propagating flame and is noncombustible and nonflammable.

RECLAMATION

Readily recoverable.

HANDLING AND STORAGE

In drums or tanks, under normal conditions.

ISOPROPYL ALCOHOL

(Isopropanol, 2-Propanol, Secondary Propyl Alcohol, Dimethylcarbinol)

$CH_3CHOHCH_3$

EFFECTIVITY

Oils; alkaloids, gums; shellacs; rosins; mastic; waxes; some synthetic resins.

CLEANING METHODS

Cold immerse; slosh, brush, static ultrasonic agitation; automated processes not applicable.

ADVANTAGES

1. Similarity to ethyl alcohol permits its use as an alternate.
2. A good solvent within its capabilities.

DISADVANTAGES

1. Fair compatibility with normal construction materials.
2. Limited ability to dissolve inorganic solids.
3. Limited ability to remove particulate matter.
4. Greater toxicity than ethyl alcohol.

HAZARDS

Toxicity

1. TLV is 400 ppm.
2. Although safe for contact with the skin, internal consumption is unsafe.

Flammability

Flammable.

RECLAMATION

Hazardous.

HANDLING AND STORAGE

In tight containers, away from flames and under controlled temperature variations.

SPECIFICATIONS

TT-I-735a, Amendment 2, 5/5/64.

METHANOL

(Methyl Alcohol, Wood Alcohol) CH_3OH

EFFECTIVITY

Dyes; alkaloids; shellac; kauri; polyvinyl; butyrol; ethel cellulose; inks; waxes.

CLEANING METHODS

Unheated solution for dip, slosh, soak, brush, and mechanical or ultrasonic agitation. Not suitable for automated processes.

ADVANTAGES

1. Excellent solvent for such inorganics as sodium and potassium hydroxides and many salts.

DISADVANTAGES

1. Limited solubility for most vegetable oils.
2. Anhydrous methanol alcohol attacks aluminum and lead; in aqueous solution, it attacks steel.
3. Extensive industrial use restricted by high toxicity; see Hazards.

HAZARDS

Toxicity

1. Poisonous if taken orally, a few ounces being adequate to produce blindness and death.
2. More toxic than other aliphatic alcohols. Symptoms of intoxication by inhalation may include eye, nose, and throat irritation, dizziness, vertigo, headache, and sickness.
3. Often ocular disturbances will follow inhalation exposure.
4. Regular exposure to subacute doses may lead to organic damage sufficient to eventually cause death.
5. Excess skin contact should be avoided.

6. TLV is 200 ppm.

Flammability

Highly flammable.

RECLAMATION

Extremely hazardous.

HANDLING AND STORAGE

Must be in airtight containers; consigned for road or rail transport as "flammable;" stored under controlled conditions, sway from heat or flames.

SPECIFICATIONS

O-M-232d, 6-16-60.

METHYL ETHYL KETONE

(2-Butanone, Ethyl Methyl Ketone) $CH_3COCH_2CH_3$

EFFECTIVITY

Natural and synthetic vinyl resins; lacquers; varnishes; fats; waxes; oils; greases; crude rubber; shellac; bitumens and asphalts.

CLEANING METHODS

Without heat; dip, slosh, brush, and mechanical or ultrasonic agitation; must be well ventilated. Not appropriate for automation.

ADVANTAGES

1. Equivalent to acetone in cleaning power but less soluble in water; higher boiling point and a lower vapor pressure.
2. Generally noncorrosive to metals, with iron, mild steel, copper or aluminum.

DISADVANTAGES

1. See Hazards.

HAZARDS

Toxicity

1. Slightly more toxic than acetone, it is very definitely an irritant to the eyes and nose.
2. TLV is 200 ppm.

Flammability

Extremely flammable.

RECLAMATION

Hazardous.

HANDLING AND STORAGE

Must be consigned as "highly flammable for shipment." Should be stored in airtight containers, away from open flames.

SPECIFICATIONS

ASTM D740-46.

PERCHLOROETHYLENE

(Tetrachloroethylene) C_2Cl_4

EFFECTIVITY

Oils; fats; waxes; tars; resins and rubbers.

CLEANING METHODS

Vapor degreasing; dip, slosh, brush, spray, to fully automated, with full ventilation required.

ADVANTAGES

1. Higher boiling point permits parts to be more thoroughly degreased before heating up to vapor temperature.

DISADVANTAGES

1. Inhibitors and stabilizers are a problem.

2. High temperature solvent.

HAZARDS

Toxicity

1. Casual exposure is unlikely to induce injury to the system.
2. The appreciable anesthetic action demands protection against exposure to high concentrations of vapor.
3. Inhalation of vapor, greater than 100 ppm by volume, will cause irritation to the nose, throat, and eyes.

Flammability

Rated as nonflammable and nonexplosive.

RECLAMATION

May be purified and reused.

HANDLING AND STORAGE

Airtight containers

SPECIFICATIONS

FED-SPEC O-T-236a.

SYM-TETRACHLOROETHANE

(1, 1, 2, 2-Tetrachloroethane, Acetylene Tetrachloride)
$C_2H_2Cl_4$

EFFECTIVITY

Fats; oils; waxes; camphor; cellulose triacetate, and many gums and resins.

CLEANING METHODS

High toxicity has almost eliminated tetrachloroethane from the industrial scene.

ADVANTAGES

1. Excellent solvent properties.

DISADVANTAGES

1. See Hazards.
2. Exceptional ventilation facilities mandatory.
3. Too toxic for normal industrial use.

HAZARDS

Toxicity

1. Probably the most dangerous and toxic of all solvents.
2. TLV is 5 ppm.
3. More toxic than chloroform, as contact with vapors will induce abnormal fatigue and nausea.
4. Prolonged exposure to vapor will cause jaundice and liver enlargement.

Flammability

Nonflammable.

RECLAMATION

Hazardous.

HANDLING AND STORAGE

1. Slightly corrosive to metals and may be stored in mild steel or aluminum. Copper is not recommended.

2. Atmospheric moisture can produce small amounts of hydrochloric acid.

TOLUENE

(Toluol, Methylbenzene, Phenylmethane) C_7H_8

EFFECTIVITY

1. Very efficient for gums; such resins as benzyl abietate, copals, copal esters, coumarone, glyptal, sandarac, vinyl, and alkyd.
2. A solvent for oils; some cellulose acetate; many types of cellulose ethers, and chlorinated rubber.

CLEANING METHODS

1. As a cold liquid may be employed for dip, slosh, brush, and agitation applications.
2. Not applicable for automated operations.
3. Spray cleaning may be performed, but it is a hazardous operation.

ADVANTAGES

1. Good cleaning power.

DISADVANTAGES

1. See Hazards.
2. Vapor odors do not serve as a warning of high concentrations.

HAZARDS

Toxicity

1. TLV is 200 ppm.
2. The chronic toxicity of toluene is so much less than benzene that toluene appears to offer only a modest hazard for industrial use.
3. The liquid exerts a strong degreasing action on the skin, is an irritant; it is desirable to avoid liquid contact as far as is possible.

Flammability

Very flammable.

RECLAMATION

Hazardous.

HANDLING AND STORAGE

1. Not corrosive to metals. Iron, mild steel, copper, and aluminum are suitable for plant and containers.
2. Local regulations exist in many areas governing the transport, handling, and storage.

1, 1, 1-TRICHLOROETHANE

(Methyl Chloroform, Alpha-Trichloroethane) CH_3CCl_3

EFFECTIVITY

Greases; oil; tars; waxes; resins; adhesives; solder fluxes; photoresist inks.

CLEANING METHODS

Spraying, slushing, wiping, and also dipping when aided by mechanical or ultrasonic agitation.

ADVANTAGES

1. Excellent solvent power.
2. Recoverable by distillation.
3. Rapid drying.
4. As an industrial solvent, it contains an inhibitor to arrest corrosive action to materials.

DISADVANTAGES

1. Possible harmful effects on rubber and some plastics.
2. Pure trichloroethane is corrosive to many materials, especially aluminum and alloys.

HAZARDS

Toxicity

1. TLV is 350 ppm.
2. Neoprene or polyvinyl alcohol plastic gloves should be worn as a protection against skin contact.

Flammability

Nonflammable by tag closed cup, but flammable solvent/air mixtures are possible.

RECLAMATION

May be repeatedly distilled, providing inhibitor content is maintained. The disposal problem is minimized by reclamation.

HANDLING AND STORAGE

In closed containers, at controlled temperatures.

SPECIFICATIONS

FED-SPEC O-T-620a including Amendments 2 and 3.

FED-SPEC P-T-936b including Amendment 3.

TRICHLOROETHYLENE

(1, 1, 2-Trichloroethylene; 1, 2, 2-Trichloroethylene, Ethylene Trichloride) C_2HCl_3

EFFECTIVITY

Oils; fats; waxes; pitch grease; tar gum; rosin; ester gum; bitumens; dyes; caffeine; rubber, and sulphur.

CLEANING METHODS

1. All types of operations from dip to the fully automated, heated or cold.
2. Widely used as a vapor degreasing media.

ADVANTAGES

1. High solvent power.
2. Rapid penetration.
3. Good stability.
4. Low specific gravity.
5. Moderate boiling point.
6. No residue film.

DISADVANTAGES

1. See Hazards (toxicity).
2. Insoluble in water.
3. Proper inhibitor levels must be maintained to avoid acidity.
4. Strong solvent attacks elastomers and plastics.

HAZARDS

Toxicity

1. Controlled toxicity hazard when proper safety precautions are followed.
2. Inhalation of excessive amounts of vapor causes nose and throat irritation.
3. TLV is 100 ppm.
4. Prolonged or repeated skin contact can induce dermatitis due to natural skin oil removal; for protection, neoprene or polyvinyl alcohol plastic gloves, and other protective clothing should be worn.

Flammability

1. Neither flammable nor explosive by standard test methods; however, flammable vapor/air mixtures are known.

2. At very high temperatures (open flame or open electric heaters), it may decompose to give hydrogen chloride and other irritating and toxic vapors.

RECLAMATION

Responds to economical processes and readily separates from extracted matter.

HANDLING AND STORAGE

Will not attack common metals even in the presence of moisture. Storage satisfactory in airtight containers. Normal temperature ranges are adequate.

SPECIFICATIONS

FED-SPEC O-T-634b.

MIL-SPEC MIL-T-27602A.

MIL-T-7003.

TRICHLOROTRIFLUOROETHANE

CCl_2FCClF_2

EFFECTIVITY

Oils; greases, and other organics. The filling and thickening materials in some greases may not be soluble in this solvent.

CLEANING METHODS

May be employed with all types of cleaning equipment, from dip to automated. Good degreasing solvent.

ADVANTAGES

1. Chemically very stable; low temperature operation.
2. When agitation or solvent flow technique is employed, it exhibits a washing action that adds to effectiveness as a cleaning agent.
3. Steel, cast iron, brass, copper, tin, lead, zinc, aluminum, magnesium, plastic, and elastomers may be safely cleaned under normal conditions.
4. May be recovered repeatedly without change of effectiveness or danger of forming acid; no inhibitor needed.

DISADVANTAGES

1. The hands should be protected by neoprene gloves.
2. Not recommended for long exposure to galvanized or zinc alloys.
3. Compatibility with other metals is affected by the presence of water.

HAZARDS

Toxicity

1. Neoprene gloves should be worn to prevent drying of the skin, or absorption through the skin.
2. Should not be taken internally.
3. TLV is 1000 ppm.

Flammability

Underwriters Laboratories reports (MH-3072) that it is nonexplosive. They found an apparent ignition temperature of 1256°F, but the combustion was weak and very difficult to sustain.

RECLAMATION

Readily recoverable.

HANDLING AND STORAGE

In drums or tank cars; normal conditions.

SPECIFICATIONS

MIL-C-81302A.

MSFC-SPEC-237A.

TABLE 3-31

Significance of Physical Properties of Cleaning Agents

PROPERTY	PROPERTY SIGNIFICANCE AS RELATED TO CLEANING
BOILING POINT	1. Single point indicates a pure chemical compound or azeotrope, a range indicates a blend, mixture, or the presence of contamination. 2. The wider the spread of boiling points between solvent and contamination, the more effective the separation in a solvent distillation (vapor) system. 3. Establishes the operating temperature of a degreaser and therefore, (a) the degree of hazard to temperature-sensitive parts, (b) the heat dump into the surrounding environment, and (c) the cooling time required for post-cleaning processing. 4. May establish cleaning effectiveness in relation to heat-sensitive soils.
FREEZING POINT	1. A wide range between the freezing and boiling points assures sufficient operating latitude. 2. The phase change--expansion or contraction--when the freezing point is reached should be considered.
SURFACE TENSION	1. Surface tension of the solvent must be lower than the surface tension of the substrate or the soil, for effective wetting action. 2. A low surface tension permits fluids to more easily penetrate and evacuate pores, cracks, crevices, and capillaries. 3. In combination with viscosity, surface tension is indicative of (a) wettability, (b) film thickness or liquid holdup after part is cleaned and dried, and (c) the control rate at which the liquid can be handled through fine filters.
VISCOSITY	1. A measurement of pumpability and an indicator of flow characteristics and pumping requirements.
FLAMMABILITY	1. Standard tests (Tag closed cup, etc.) and values must be accepted for what they are, i.e., test results under controlled conditions. They may not be indicative of actual use conditions. 2. Some solvents with a low flash point (Heptane) pass through the flammability range so quickly that they offer less real hazard in use than some of those with higher flash points (kerosene). 3. Flammability may increase as a solvent is used and some constituents are evaporated.
TLV	1. Threshold limit values (TLV) have been established as a guide to a human tolerance of toxicity with exposure 8 hours a day, 6 days a week, for extended periods. 2. The human body can tolerate more than the TLV for very short periods, usually without adverse effect. 3. Any cleaning facility should be designed to operate below the TLV, and not at or above it. 4. The value of 1000 is the largest value used in this rating system. 5. These values in the past were referred to as the maximum allowable concentration (MAC) as specified by the American Conference of Governmental Industrial Hygienists.
SPECIFIC HEAT	1. Defined as the thermal capacity of a liquid as a ratio to that of water at 15°C. 2. In combination with latent heat, indicates the utility requirements to raise the temperature of a liquid to the boiling point.
LATENT HEAT	1. Expressed as calories of heat required to change 1 gram of liquid to vapor at the boiling point. 2. In combination with specific heat, indicates the heat needed to dry a part by evaporation. 3. The three factors to be considered are the specific and latent heats of the liquid and the specific heat of the part.
SOLVENT CHEMISTRY	1. Basically, the solvent selected should have the ability to dissolve the soil to be removed without damaging the materials of construction. The kauri-butanol value is <u>one</u> means of estimating this ability.

TABLE 3-32

Effects of Common Cleaning Solvents on Materials

		EFFECT ON MATERIALS OF CONSTRUCTION			
		Plastics			
Chlorinated Hydrocarbons	Federal or MIL Specification	Polystyrene	Polyvinyl Chloride	Polyethylene	Bakelite (Phenolic)
Methylene chloride (dichloromethane, technical)	MIL-D-6998A-1 Grade A - 0.005% max acidity Grade B - 0.010% max acidity	Dissolves	Will damage	Will damage on prolonged contact	None
Trichloroethylene, technical	O-T-634a Type I - Regular Type II - Stabilized for vapor degreasing (Supersedes MIL-T-7003)	Dissolves	4 hours - swollen	4 hours - slight effect	None
1, 1, 1-trichloroethane, technical inhibited (inhibited methyl chloroform)	O-T-620a-2 (Supersedes Safety Solvent MIL-S-18718(Aer)-1 which consisted of 70% mineral spirits, 25% methylene chloride, 5% perchloroethylene)	Dissolves	1 hour - none 4 hours - slight swell	1 hour - none 4 hours - slight swell	None
Carbontetrachloride, technical grade (tetrachloromethane)	O-C-141 (Canceled)	Dissolves	5 min - none	5 min - slight swell	None
Blend of chlorinated solvents (composition proprietory)		Dissolves	10 min - none	1 hour - none 4 hours - slight swell	None
Perchloroethylene (tetrachloroethylene, technical grade)	O-T-236a (Supersedes O-P-191a)	Dissolves on long exposure	4 hours - none	4 hours - slight effect	None
Aromatic Petroleum					
Benzene, technical (benzol)	VV-B-231c Grade A - Industrial-grade benzene Grade B - Industrial-90 benzene	Dissolves			
Toluene, technical (toluol)	TT-T-548c	Dissolves			
Xylene (xylol)	TT-X-916b	Dissolves			
Naptha, aromatic (distilled from petroleum)	TT-N-97b Type I - Boiling range (190°-284°F) Grade A - high solvent power Grade B - low solvent power Type II - Boiling range (265°-376°F) Type III - Boiling range (340°-425°F)				

TABLE 3-32
(continued)

EFFECT ON MATERIALS OF CONSTRUCTION								
Elastomers			Wire Coatings, Insulating Varnishes, and Marking Inks					
Teflon TFE	Neoprene Rubber	Silicon Rubber	Formvar Polyvinyl Formal	Bondar	Glyptal 1201 Air-Dried	Glyptal 1202 Air-Dried	GE 9740 Baked	Ink
None	Swells	Swells	Severe crazing	Slight effect	Lifted	Lifted	Lifted	Removed
None	Swells	Swells	Will soften	None	Lifted	Lifted	Lifted	Removed
None	3 min - none 5 min - slight swell	3 min - none 5 min - swell	5 min - none	5 min - none	5 min - none	5 min - lifted	5 min - lifted	Some removed (will not remove epoxy-based ink
None	5 min - swell	Swells	Slight effect	None	Slight effect	Slight effect	Slight effect	Partially removed
None	5 min - slight swell	Swells	5 min - none	5 min - none	5 min - none	5 min - lifted	5 min - lifted	Partially removed
None	Swells on prolonged contact	Swells	None	None	None	Slight effect	Slight effect	Partially removed
	Dissolves							
	Dissolves		1 hour - softened					
			1 hour - solvent discolored indicating resin extraction					

TABLE 3-32
(continued)

		EFFECT ON MATERIALS OF CONSTRUCTION			
		Plastics			
Fluorinated Hydrocarbons	Federal or MIL Specification	Polystyrene	Polyvinyl Chloride	Polyethylene	Bakelite (Phenolic)
Trichloromonofluoromethane (fluorocarbon 11) (solvent grade)		Dissolves on long exposure	Slight effect	Slight effect	None
Trichlorotrifluoroethane (fluorocarbon 113) (solvent grade)	MIL-C-81302 Wep (Covers Freon PCA and equivalent grade solvents; is being revised to also cover Freon TF and equivalent grade solvents)	4 hours at 75°F - none 4 hours boiling - cracked and brittle	4 hours - none	4 hours - none	None
Aliphatic Petroleum					
Naptha, aliphatic (petroleum naptha)	TT-N-95a Type I - For organic coating Type II - For cleaning acrylic Type plastics				
Stoddard solvent (dry cleaning solvent)	P-D-680 (Supersedes P-S-661b) Type I - 100°F min flashpoint Type II - 140°F min flashpoint	5 min - none	None	None	
Mineral spirits Thinner; paint, volatile spirits (petroleum spirits)	TT-T-291c Grade 1 - Light thinner Grade 2 - Heavy thinner				
Oxygenated Solvents*					
Isopropyl alcohol (antiicing fluid and solvent)	TT-I-735a (Supersedes MIL-F-5566 and MIL-I-10428A) Grade A - 0.1% max water; for use in manufacturing Grade B - 0.4% max water; for use as antiicing fluid and solvent	5 min - none	5 min - extracts plasticizer	None	None
Methyl alcohol (methanol)	O-M-232d Grade A - 99.8% synthetic (solvent use) Grade AA - 99.8% synethetic ($H-CO_2$ generators) Grade B - 99% technical (solvent use) Grade C - wood alcohol (denaturing grade)	5 min - None	5 min - extracts plasticizer	None	None
Ethyl alcohol (ethanol)	O-E-760b (Supersedes O-A-396)	5 min - none	5 min - extracts plasticizer	None	None
Acetone, technical	O-A-51d	Dissolves	Dissolves	None	Dissolves

Source: "Cleaning Electronic Components," Jennings, R. L., Digest of Naval Aviation Wespons Systems; June 1966.

*Effects data determined by Sandia Laboratory, Albuquerque, New Mexico.

TABLE 3-32
(continued)

EFFECT ON MATERIALS OF CONSTRUCTION								
Elastomers			Wire Coatings, Insulating Varnishes, and Marking Inks					
Teflon TFE	Neoprene Rubber	Silicon Rubber	Formvar Polyvinyl Formal	Bondar	Glyptal 1201 Air-Dried	Glyptal 1202 Air-Dried	GE 9740 Baked	Ink
None	Slight swell	Slight swell						
None	1 hour - none	1/2 hour - 6% swell	100 hours - none	100 hours - none	Unknown	Unknown	Unknown	None
None	None	None	None	None	None	None	None	None
None	None	None	None	5 min - none	5 min - none	5 min - none	10 min - none	Varies with ink
None	None	None	None	5 min - none	5 min - none	5 min - none	10 min - none	Varies with ink
None	None	None	None	5 min - none	5 min - none	5 min - none	5 min - none	Varies with ink
None	Swells	Extracts plasticizer	None	5 min - none	Dissolves	Dissolves	Dissolves	Removes

TABLE 3-33

Comparison of Common Cleaning Media for Cleaning Precision Electronic Components*

Cleaning Media and Formula	Remove Organic Liquids	Remove Organic Solids	Dissolve Inorganic Solids	Inorganic Liquid Silicone Oils	Remove Particulate Matter	Purity	Chemical Stability	Equipment Considerations
Alcohols								
Methyl alcohol CH_3OH	Yes	Yes	Limited	Yes	Fair	Fair	Fair	Cold cleaner. Dip, slosh, brush, static ultrasonic tank. Recovery hazardous. Not applicable for automation.
Ethyl alcohol anhydrous C_2H_5OH	Yes	Yes	Limited	Yes	Fair	Good	Fair	
Isopropyl alcohol $(CH_3)_2CHOH$	Yes	Yes	Limited	Yes	Fair	Fair	Good	
Butyl alcohol C_4H_9OH	Yes	Yes	Limited	Yes	Fair	Fair	Good	
Aliphatic Petroleum Solvents								
Stoddard solvent	Yes	Limited	No	Yes	Poor	Poor	Good	Same as alcohols. Spray cleaning performed but hazardous.
"Varsol"	Yes	Limited	No	Yes	Poor	Poor	Good	
VM&P naphtha	Yes	Limited	No	Yes	Poor	Poor	Good	
Aromatics								
Benzene C_6H_6	Yes	Yes	No	Yes	Poor	Poor	Good	Same as above.
Toluene $C_6H_5(CH_3)$	Yes	Yes	No	Yes	Poor	Poor	Good	
Xylene	Yes	Yes	No	Yes	Poor	Poor	Good	
Chlorinated Hydrocarbons								
Trichloroethylene C_2HCl_3	Yes	Yes	No	Yes	Good	Good	Fair	Equipment from dip to fully automated available. Inhibitors and stabilizers are a problem. Ventilation and safety precautions are necessary.
Perchloroethylene C_2Cl_4	Yes	Yes	No	Yes	Good	Good	Good	
Methyl chloroform CCl_3CH_3	Yes	Yes	No	Yes	Good	Good	Fair	
Methylene chloride CH_2Cl_2	Yes	Yes	No	Yes	Good	Good	Good	

*Extracted from the paper "Solvents for the Cleaning of Precision Electronic Components," by D. L. Kjelleren and W. R. Steinacker, presented at the National Electronic Packaging and Production Conference, Long Beach, California, February 1967.

TABLE 3-33 (continued)

Cleaning Media and Formula	Remove Organic Liquids	Remove Organic Solids	Dissolve Inorganic Solids	Inorganic Liquid Silicone Oils	Remove Particulate Matter	Purity	Chemical Stability	Equipment Considerations
Chloroform $CHCl_3$	Yes	Fair	No	Yes	Fair	Good	Fair	
Carbon tetrachloride CCl_4	Yes	Yes	No	Yes	Fair	Good	Good	
Trichlorotrifluoroethane $C_2Cl_3F_3$	Yes	Fair	No	Yes	Very good	Excellent	Excellent	Equipment from dip to fully automatic available. Latest designs to take advantage of "stage cleaning" and water displacement are among the most modern on market. Recovery makes solvent costs very economical.
<u>Fluorinated Hydrocarbon Blends</u>								
"Freon" TMC Azeotrope "Freon" TF 50%/methylene chloride 50%	Yes	Yes	No	Yes	Very good	Good	Very good	
"Freon" T-WD 602 water dispersion 91.5% "Freon" TF/ 2.5% detergent/ 6% H_2O	Yes	Fair	Yes	Yes	Good	Poor	Very good	
"Freon" T-P 35 blend 65% "Freon" TF/ 35% isopropyl alcohol	Yes	Yes	Fair	Yes	Good	Good	Very good	
<u>Ketones</u>								
Acetone - CH_3COCH_3	Yes	Yes	No	Yes	Poor	Good	Good	Same as alcohols.
Methyl ethyl ketone $CH_3COC_2H_5$	Yes	Yes	No	Yes	Poor	Fair	Good	
<u>Water</u>								
Tap water - H_2O	No	No	Yes	No	Fair	Fair	Excellent	Good equipment available. Number of operations including driers makes equipment investment high. Automation somewhat limited.
Deionized	No	No	Yes	No	Fair	Very good	Excellent	
Distilled	No	No	Yes	No	Fair	Very good	Excellent	
Water + surfactant	Fair	Limited	Yes	No	Good	Poor	Varies	

Table 3-34 lists some of the cleaning agents that are commonly associated with the better known cleaning methods. This information should be used as a guide. It is further suggested that the technical services of cleaning agent manufacturers be used in making a final selection.

TABLE 3-34

Cleaning Agents and Compatible Cleaning Methods

Cleaning Agent	Cleaning Method	Remarks
Tap water	Soak, brush, spray, dip, rinse	Removes some gross soil; not too effective; main constituent of other solutions.
Deionized water	Ultrasonic, dip, spray, rinse	Costly equipment, used for precision cleaning applications.
Deionized water plus surfactants and/or detergents	Primarily ultrasonic	May be used in combination with some solvents.
Acidic solutions	Dip, soak, spray, mechanical washers, ultrasonic	Strong solutions for gross cleaning; mild for precision or ultrasonic.
Alkaline solutions	Dip, soak, spray, mechanical washers	Gross cleaning according to strength used; used with other agents.
Fluorinated hydrocarbons	Ultrasonic, vapor degrease, spray, flush, combinations	Higher cost offset by redistillation and reuse, and effectiveness.
Chlorinated hydrocarbons	Dip, soak, spray, vapor degrease, ultrasonic	Generally good cleaning properties; can be redistilled and reused; high toxicity.
Alcohols	Ultrasonic, wipe, dip	May be used pure or in combination with other agents; aids drying.
Ketones	Dip, soak, brush	High solvency power; some flammability and toxicity hazard.
Aliphatic hydrocarbons	Dip, soak, brush	Primarily used for gross cleaning; very selective solvents; highly flammable.
Ethers and esters	Dip, soak, brush, spray, mechanical washers	Wide range of general purpose and specialized cleaners.
Aromatics	Dip, soak, brush, spray	High solvency for some soils; flammable and toxic.

3.5.6 Aqueous Cleaning Solutions

Aqueous cleaning solutions are widely used and under certain conditions may be effective for nearly any kind of cleaning need. They are generally considered to be most applicable for the removal of heavy soils yet may be equally applicable for precision ultrasonic cleaning solutions. Aqueous solutions are compatible with nearly all accepted cleaning methods, with the exception of vapor degreasing. They may be used cold, hot, with or without agitation, or in an electrocleaning bath. Some contain surfactants or emulsifiers.

An extremely wide range of products is available from commercial producers. Each producer offers many proprietary or special formulations for both general and specific cleaning applications. For this reason, no attempt is made to itemize these products. General information, however, is contained in Table 3-35.

TABLE 3-35

General Categories of Aqueous Cleaning Solutions

General Type Cleaner	May be Used on*	Soils Removed
Alkaline	Ferrous metals, aluminum, magnesium, cadmium, zinc, and copper alloys	Light and heavy greases and oils, drawing compounds, carbon, fingerprints, metal chips, marking inks, and shop soils.
Acid	Aluminum and aluminum alloys, ferrous metals, cadmium, bronze, brass, and copper alloys	Rust, scale, corrosion products, welding flux residues, grease, and shop soils
Carbon removers (combinations)	All metals as recommended by manufacturer	Heavy carbon, varnish, gums, paint, heat-hardened resins, heavy grease, baked on, and other obdurate soils
Emulsion	Most metals, paint, varnish, decals, plastic, leatherette	Oil, light grease, identification inks

*Caution must be exercised when using alkaline or acid cleaners with aluminum and magnesium. Special formulations are available, however, for this purpose. Trial-run applications are recommended.

3.5.7 Solvent Reclamation and Purity

Some cleaning agents have a potential for reuse through reclamation processes. The primary means of reclamation are filtration to remove particulate matter and agglomerated soils and distillation to remove both particulate and dissolved contaminates.

Filtration is usually a continuous process which is operated simultaneously with cleaning. It is normally associated with vapor degreasing, ultrasonic cleaning, and most mechanized cleaning systems. A high filtration capacity is desirable, although the rate of flow must be regulated in ultrasonic cleaners so as to not disturb the cavitation process. Filtration is also employed at reclamation facilities, but usually this is a batch-type operation.

Distillation, like filtration, is also a continuous process when used in conjunction with a cleaning operation. It is limited, however, to vapor degreasing and to ultrasonic cleaning where a vapor phase is used in conjunction with an ultrasonic tank. Or it may utilize an auxiliary still operating in a loop with a dip or flush cleaning system. Consequently, the solvents redistilled in this manner are limited to the chlorinated and fluorinated hydrocarbons. Caution should be exercised due to the depletion of inhibitors or buildup of acidity in an inhibited chlorinated solvent system.

Distillation is also used in reclamation facilities which specialize in the reclamation of used solvents. In this case a semicontinuous or batch-type operation is used. Solvent reclamation, while important to maintaining a high purity level, is primarily an economic consideration and is generally limited to the relatively higher priced solvents.

As much as possible, all solvents should be kept free of water while they are being used. This can be accomplished by mechanical water separators or desiccant dryers. An exception is noted in the use of water displacement solvents or perchloroethylene dryers with a mechanical water separator.

Among solvent manufacturers, practice varies as to the method and terminology for specifying grades of purity. In general, the highest purity solvents are designated as technical or precision grades, while those with a slightly lower purity are designated as standard or commercial grades. In some cases, alphanumeric combinations (LR1, LR2) are used to designate levels of purity. It is recommended that individual solvent specifications be reviewed for more specific data regarding impurity, particulate, and nonvolatile residue content before purchases are made. Subsequent laboratory analysis may be needed depending on cleanliness requirements. It is possible to attain purity levels in reclaimed solvents comparable to that of new solvents, but other factors should be closely monitored (see Paragraph 4.2.2).

3.5.8 Handling and Storage

Handling and storage techniques, equipment, and facilities must be adapted to specific requirements related to:

a. Types of cleaning agents to be handled

b. Volume or quantity

c. Usage rate

d. Purity requirements

e. Hazards involved.

High purity solvents of technical or precision grade are normally packaged by the manufacturer in specially cleaned cans or drums under clean room conditions. The larger the container, the easier it is for the manufacturer to achieve precision-grade quality. This extends to bulk handling where the truck (shipping container) is equipped with proper filtering equipment.

In normal storage situations, drums should be stored in separate, fireproof buildings at temperatures between 40° and 90°F. Outdoor storage is acceptable for some solvents, depending on their chemical composition. Care should be taken when transferring solvents from drums to laboratory or production facility containers not to introduce contamination through handling procedures or equipment.

Bulk storage entails many special requirements, similar in some respects to large-scale hydraulic systems. The decision to install a bulk system will depend primarily on the usage rate and the economics involved. Purity requirements will also have a bearing on this decision. It should be noted that purity requirements may require special filtration or redistillation, if feasible, prior to use.

Table 3-36 presents some of the factors to be considered in bulk solvent systems.

> CAUTION: These data are listed for information only. Any installation must consider the specific solvent, its affect on materials of construction, and any special hazards or conditions associated with the solvent and its use.

3.5.9 Hazards and Cautions

The hazards and cautions associated with cleaning agents may be considered in three general groupings. These are:

a. Toxic or other effects which may be harmful to operating personnel or other personnel in the immediate or adjacent working areas.

b. Harmful effects of cleaning agents on the materials of construction of the parts being cleaned.

c. Potential explosive and fire hazards presented by some solvents.

Tables 3-37 and 3-38 contain information which will be helpful in determining precautions to be taken in the handling and use of various cleaning agents.

TABLE 3-36

Selection of Materials for Bulk Solvent Systems

Equipment	Material of Construction	Features and Use Considerations
Storage tank	Steel plate, 1/8 to 1/4 inch thick depending on capacity	Should be free of rust, weld scale, and moisture. Should be equipped with access manholes, pressure-vacuum relief valves, dryers, fill and drain outlets, sight glass or level gage, and grounding rods.
Dryers	Calcium chloride, silica gel	Especially needed for chlorinated solvents. Prevents introduction of moisture caused by liquid volume changes due to temperature changes, and filling and withdrawal.
Filters	Wire mesh or sintered metal, cellulose, nylon, Teflon, PVC	Use depends on purity requirements. Normally more than one type of filter is used in outlet lines downstream from pumps and valves.
Gaskets and packing	Reinforced metal asbestos, Teflon, Teflon-impregnated asbestos	Should be inspected periodically for leakage or wear.
Hose	Flexible stainless steel or bronze	Some synthetic materials are acceptable for certain solvents. Should be fitted with quick-acting couplings.
Nozzles	Stainless steel, brass or bronze	Chrome-plated materials are acceptable.
Piping	Seamless black steel	Welded fittings and connections are preferred. Threaded connections should be overwrapped with Teflon tape to prevent leaks; unions should have ground joints.
Pumps	Cast iron, stainless-steel shafts	Mechanical seals are preferred. Lubricated seals require solvent-resistant greases.
Valves	Iron or bronze, stainless-steel or nickel-alloy seats	Globe valves are preferred where throttling or frequent intermittent operations are required; gate valves are used for full flow conditions. Stainless-steel ball valves with Teflon seats are used for high purity systems. Swing and lift check valves are used to prevent reverse flow.

NOTE: Manufacturer's instructions should be observed in the handling and storage of all solvents. Local laws and ordinances should also be known and observed. Aluminum, magnesium, and zinc are not generally recommended for use as materials of construction in solvent systems.

TABLE 3-37

Personnel Precautions for Selected Classes of Cleaning Agents

Class of Cleaning Agent	Avoid Long Skin Exposure or Eye Contact	Avoid Skin or Eye Exposure and Breathing Vapors	Very Hazardous--Avoid Contact with Liquids or Vapors--Wear Protective Goggles, Gloves, and Clothing
Water soluble acids			X
Acid solvent formulations			X
Surfactants	X		
Mild alkaline	X		
Heavy alkaline		X	
Caustic removers and strippers			X
Detergents and soaps	X		
Halogenated solvents		X	
Solvent blends and mixtures		X	
Emulsifiable oils		X	
Fractionation by-products		X	
Rust preventatives	X		

TABLE 3-38

Danger Points of Common Solvents

Solvent	Flash Point (°F)	Ignition Point (°F)	Explosive Limits[1]		Threshold Limit Values		Toxicity[2]
			Lower	Upper	PPM	Mg/CuM	
Acetal	-5	446	1.6	10.4			B-C-D
Acetaldehyde	-36	365	4.1	55.0	200	360	A-B-C-D
Acetic acid	104	800	5.4		10	25	A-B-D
Acetic anhydride	121	600	2.7	10.0	5	20	A-B-C-D
Acetone	0	1000	2.5	12.8	1000	2400	B-D
Allyl alcohol	70	713	2.5	18.0	5	12	A-B-C-D
Amyl acetate	77	750	1.1		200	1050	A-C-D
Amyl alcohol	100	700	1.2				A-B-C-D
iso-Amyl alcohol	109	650	1.2		100	360	A-B-C-D
Amyl chloride	55	650	1.6	8.6			
ter-Amyl chloride		649	1.5	7.4			
Amyl formate							A-C-D
Amyl lactate							A-B-C-D
Amyl propionate	106						A-B-C-D
Benzene	12	1000	1.4	7.1	25	80	A-B-C-D
Benzyl acetate	216	862					A-C-D
Benzyl alcohol	213	817					A-B-C-D
Benzyl bromide							A-C-D
Benzyl cellosolve	265	665					A-C-D
Benzyl formate							None
Butyl acetate	72	790	1.7	7.6	200	950	A-B-C-D
iso-Butyl acetate	64						A-B-C-D
Butyl alcohol	84	650	1.4	11.2	100	300	A-C-D
iso-Butyl alcohol	82	800	1.7				A-C-D
sec-Butyl alcohol	75	777					A-C-D
Butyl benzene	160	774	0.8	5.8			A-B-C-D
Butyl butyrate	128						
Butyl carbitol	172	442					A
Butyl cellosolve	141	472	1.1	10.6	50	240	A-C-D
Butyl cellosolve acetate	180						A-B-C-D
Butyl chloride	20	860	1.8	10.1			B
Butyl formate	64	612	1.7	8.0			A-C-D
Butyl lactate	160	720					B-C
Butyl propionate	90	800					
Carbitol	201						A-B-C-D
Carbitol acetate	225						A-B-C-D
Carbon disulfide	-22	212	1.2	44.0	20	60	A-B-C-D
Carbon tetrachloride	None	None			25	160	A-B-C-D
Cellosolve	104	406	1.8	14.0	200	740	A-C-D

TABLE 3-38
(continued)

Solvent	Flash Point (°F)	Ignition Point (°F)	Explosive Limits[1] Lower	Explosive Limits[1] Upper	Threshold Limit Values PPM	Threshold Limit Values Mg/CuM	Toxicity[2]
Cellosolve acetate	124	715	1.7		100	540	A-B-C-D
Chlorobenzene	85	1100	1.3	7.1	75	350	A-B-C-D
Chloroform	None	None			100	490	A-C-D
Cresol	178	1100	1.1		5	22	A-B-C-D
Cumene	102						A-B-C-D
Cyclohexane	1	514	1.3	8.0	400	1400	B-C-D
Cyclohexanol	154				100	410	A-B-C-D
Cyclohexanone	147	847	1.1		100	400	A-B-C-D
Cyclohexene	-21				400	1350	A-B-C-D
Cyclohexyl acetate	136						A-B-C-D
Cyclohexylamine	90	560					A-B-C-D
Cyclohexyl formate							A-C-D
Cyclopentane	20[4]						A-B-C-D
Decahydronaphthalene	136	504					A-B-C-D
Decalin	136						A-B-C-D
Diacetone alcohol	148	1118			50	240	A-B-C-D
Diamyl phthalate	245						A-B-C-D
o-Dichlorobenzene	151	1198	2.2	9.2	50	300	A-B-C-D
Dichlorodifluoromethane	None	None			1000	1950	C-D
Dichloroethane	56	775	6.2	16.00	100	400	A-B-C-D
Dichloroethyl ether	131	696			15	90	A-B-C-D
Dichlorohydrin	165						A-C
Dichloromethane (methylene chloride)	None	1224	15.5[3]	66.0[3]	100	210	A-B-C-D
Diethanolamine	280	1224					B-C
Diethyl benzene	132	806					A-B-C-D
Diethyl carbonate	77						A-B
Diethyl cellosolve	95	406					A-C-D
Diethyl exalate	168						C-D
Diethyl phthalate	243						A-B-C-D
Dimethoxymethane	0						A-B-C-D
Dimethyl cyclohexane	52						A-B-C-D
Dimethyl sulfate	182				1	5	A-B-C-D
Dioxane	54	356	2.0	22.0	100	360	A-C-D
Dipetene	108						A-B-C-D
Diphenyl	235	498					C-D
Dipropylene glycol	244						A-C
Ethyl acetate	24	800	2.5	9.0	400	1400	A-B-C-D
Ethyl alcohol	55	793	4.3	19.0	1000	1900	A-B-C-D

TABLE 3-38
(continued)

Solvent	Flash Point (°F)	Ignition Point (°F)	Explosive Limits[1]		Threshold Limit Values		Toxicity[2]
			Lower	Upper	PPM	Mg/CuM	
Ethyl benzene	59	870	1.0		200	870	A-B-C-D
Fthyl bromide	None	952	6.7	11.3	200	890	A-B-C-D
Ethyl chloride	-58	966	3.8	15.4	1000	2600	A-B-C-D
Fthyl cyclohexane		504	0.9	6.6			A-B-C-D
Ethylene chlorohydrin	140	797	4.9	15.9	5	16	A-B-C-D
Ethylene dichloride	56	775	6.2	16.0			A-B-C-D
Fthylene glycol	232	775	3.2				A-C-D
Ethyl formate	-4	1071	2.7	13.5	100	300	A-B-C-D
Ethyl lactate	115	752	1.5				A-B-C-D
Gasoline	-45	536	1.4	7.6	500	2000	A-B-C-D
Glycerine	320	739					A
Heptane	25	452	1.2	6.7	500	2000	C-D
iso-Heptane	0[4]		1.0	6.0			C-D
Heptene	20[4]						A-B-C-D
Hexane	-15[4]	500	1.2	7.5	500	1800	A-B-C-D
Hexyl acetate	113						A-B-C-D
Isophorone	205	864			25	140	A-B-C-D
Mesityl oxide	87	652			50	200	A-B-C-D
Methyl acetate	14	850	3.1	16.0	200	610	A-B-C-D
Methyl alcohol	52	867	7.3	36.0	200	260	A-B-C-D
Methyl cellosolve	105	551	2.5	19.8	25	80	A-B-C-D
Methyl cellosolve acetate	132		1.7	8.2	25	120	A-B-C-D
Methyl cyclohexane	25		1.2		500	2000	B-C
Methyl cyclohexanol	154				100	470	A-C-D
Methyl cyclohexanone	118				100	460	A-B-C-D
Methyl ethyl benzene							A-B-C-D
Methyl formate	2	840	5.9	20.0	100	250	A-B-C-D
Methyl heptane							A-B-C-D
Naphtha (petroleum)	0	475	1.1	5.9	500	2000	A-B-C-D
Nitrobenzene	190	900	1.8		1	5	A-B-C-D
Nitrobutane							A-C-D
Nitromethane	95	785			100	250	A-B-C-D
1-Nitropropane	120	789					A-C-D
Paraldehyde	63	460	1.3				B
Pent-acetate	98						A-B-C-D
Pentachloroethane							A-B-C-D
Pentane	-40	588	1.5	7.8	1000	2950	A-B-C-D
Perchloroethylene	None				200	1350	A-B-C-D

3.5.9.1 General Cleaning Agent Safety Rules

a. Provide adequate ventilation.

b. Always store new or used solvents in clearly labeled containers.

c. Provide eye flooding and shower facilities as needed.

d. Keep container rings and openings sealed when not in use.

e. Avoid prolonged or repeated contact with the skin or breathing of vapors.

f. Prohibit smoking, welding, or use of open flame in the vicinity of chlorinated solvents.

g. Dispose of contaminated solutions in accordance with local health regulations.

h. Do not take internally.

i. Use protective devices as required, i.e., cover or cup-type goggles, face shields, solvent resistant gloves, and other protective clothing.

j. When entering any type tanks which have contained cleaning agents, observe the following rules:

   (1) Remove all of the cleaning agent possible.

   (2) Aerate thoroughly with fresh air before entering and continue aeration while tank is occupied.

   (3) Use rescue harness and lifeline as needed.

   (4) Provide a second man at all times to observe the man in the tank.

   (5) Provide gas or hose masks or other breathing apparatus as needed.

k. When mixing strong acid or alkaline solutions, always add the acid or alkali to water. Never add water to acids or alkalies.

l. Combinations of highly reactive materials (sodium, potassium, barium, magnesium, aluminum) with fluorocarbons and halocarbons are capable of producing detonations on impact. This capability is increased at high temperatures or when the material is finely powdered.

TABLE 3-38
(continued)

Solvent	Flash Point (°F)	Ignition Point (°F)	Explosive Limits[1] Lower	Upper	Threshold Limit Values PPM	Mg/CuM	Toxicity[2]
Propyl acetate	58	842	2.0	8.0	200	840	A-B-C-D
Propyl alcohol	59	700	2.1	13.5			A-B-C-D
iso-Propyl alcohol	53	750	2.0	12.0	400	980	A-B-C-D
Propyl benzene	86						A-B-C-D
Propyl chloride	0[4]		2.6	11.1			A-B-C-D
iso-Propyl ether	-81	830	1.4	21.0	500	2100	A-B-C-D
Propylene dichloride	60	1035	3.4	14.5	75	350	A-B-C-D
Pyridine	68	900	1.8	12.4	10	30	A-B-C-D
Stoddard solvent	100	450	1.1	6.0	500	2900	A-B-C-D
Tetrachloroethane					5	35	A-B-C-D
Tetrahydronaphthalene	171						A-B-C
Toluene	40	1026	1.4	6.7	200	750	A-B-C
Trichloroethylene	None	770			200	1050	A-B-C-D
Triethanolamine	355						A
Triethylene glycol	350	700	0.9	9.2			A
Trimethylcarbinol	52	900	2.3	8.0			A-B-C-D
Turpentine	95	464	0.8		100	560	A-B-C-D
Vinyl acetate	18	800	2.6	13.4			A-B
Vinyl chloride	0[4]		4.0	22.0	500	1300	A-B-C-D
Vinyl ethyl ether	-50[4]	395					A-C-D
White spirit	80						A-B-C-D
Xylene	63	900	1.0	6.0	200	870	A-B-C-D
Xylidene	206						A-B-C-D

[1]Explosive limits shown represent percent by volume.

[2]A - possible hazard to eyes; B - possible hazard to skin; C - possible hazard to entire system (organs, blood, general health); D - possible hazard to bronchial system (whole breathing apparatus).

[3]Explosive limits apply only when the solvent is used in oxygen.

[4]Something less than degree shown.

(Reprinted with permission from "Chemicals for Ultrasonic Cleaning," Branson Instruments, Inc., November 1960.)

3.5.9.2 First Aid and Treatment

Table 3-39 presents a general treatment guide for overexposure to cleaning solvents. IT IS RECOMMENDED THAT MORE SPECIFIC FIRST AID PROCEDURES BE DEVELOPED AND POSTED IN THE IMMEDIATE WORK AREA FOR EACH TYPE OF SOLVENT USED.

TABLE 3-39

First Aid Treatment Guide

Type of Contact	Symptoms	Treatment
Inhalation	Anesthetic or narcotic effect. Varies from irritation of nose and throat to dullness, dizziness, headache, stupor, nausea, vomiting, and unconsciousness or death in severe exposures.	Remove to fresh air; obtain immediate medical attention; administer artificial respiration if breathing has stopped; keep patient warm and quiet. Usually do not give adrenalin or epinephrine.
External contact		
Skin	Burning sensation, dermatitis	Remove any soaked clothing; wash affected area; apply lanolin ointment, olive oil, or cold cream. Secure medical attention.
Eyes	Pain, inflammation, lacrimation	Flush eyes with large amounts of water; call a physician at once.
Oral intake	Nausea, vomiting, and diarrhea; drowsiness or unconsciousness	Call a physician at once; induce vomiting.

3.6 Verification of Surface Cleanliness

Perhaps no other aspect of contamination control is as controversial or undeveloped as verification of surface cleanliness. Many people have tried to answer the question, "How clean is clean?" The hours of discussion devoted to this question, though somewhat fruitless, are indicative of the interest and the need for additional research and development. From one of these discussions may eventually come the spark of an idea which will evolve into a relatively simple, easy to administer, reliable, and repeatable surface cleanliness test method.

A much more pertinent question is, "How clean does a part have to be to function properly and reliably?" The area of attention is thus immediately directed from generalities to specifics. In the case of microminiature electronic components, the answer to this question may not be too difficult to determine. In most other cases, however, the answer may be vague or even unknown.

It is common practice to attempt to achieve the highest practical cleanliness level. Disregarding appearance, if the part then functions properly, some reduction in cleanliness requirements may be justified. With one exception, the determining factor in establishing cleanliness requirements is function. The exception concerns microbial decontamination in the medical, pharmaceutical, and planetary quarantine fields, in which the highest attainable cleanliness levels are desired.

3.6.1 Classification of Surface Cleanliness Tests

Apparently, the absence of any universal surface cleanliness test has lead to the development of many tests which exhibit varying degrees of effectiveness and application. There are at least several ways of classifying these tests, some of which are described below.

One method of classification involves direct and indirect methods for determining the degree of cleanliness. These methods are summarized in Table 3-40.

TABLE 3-40

Comparison of Direct and Indirect Surface Cleanliness Tests

Type of Test	Parameter Measured	Characteristics of Test
Direct	Presence or amount of soil remaining on a surface.	The only true methods of testing for surface cleanliness; vary widely in discrimination and application; laboratory and production.
Indirect: soil removed	Amount of soil removed from a surface.	Widely used; more suitable to laboratory methods; more a measure of the effectiveness of the cleaning system than of the exact cleanliness of a surface.
Indirect: effects	Effects of unclean surfaces.	Visual means determine blemishes or irregularities in subsequent operations such as plating; malfunction or failure may be the indirect result.

Other methods of classifying surface cleanliness tests include the following:

a. Qualitative Versus Quantitative -- Most tests provide qualitative results.

b. Laboratory Versus Production -- Generally the more accurate tests require the use of laboratory techniques and are therefore not suitable as tests which can be performed on the production line.

c. Hydrophobic Versus Hydrophilic -- Some tests are sensitive to only hydrophobic or hydrophilic soils, while others are sensitive to all soils.

d. Degree of Sensitivity -- Varies widely among different tests.

Many tests have been designed to provide a measure for surface cleanliness. A lesser number have been developed to a point of practical usefulness. Of those so developed, most have one or more limitations which prevent them from becoming a universally applicable and accepted surface cleanliness test.

A listing and brief description of those tests which are recognized as having application in this field are shown in Table 3-41.

3.6.2 ASTM Test Methods

The American Society for Testing and Materials has developed a number of test procedures related to the field of surface cleanliness. For reference purposes, some of these tests are listed in Table 3-42.

TABLE 3-41

Specific Surface Cleanliness Tests

Name of Test	Test Method	Characteristics or Limitations
Visual	Examination with the unaided eye or with a microscope.	Subjective but widely used; most effective with particulate matter, least effective with invisible films; use of a highly trained microscopist increases the validity of test results.
Tissue paper or white cloth	Surface is rubbed with a piece of white tissue paper or a white cloth. Grease or soot is observable.	Limited to visible soils; relatively insensitive qualitative test.
Water break	Normally applied after last clean water rinse. Any break in continuity or receding water film is observed as water drains off the part.	A qualitative test for hydrophobic soils; contaminants in the water lessen sensitivity; use of deionized water and a trained inspector may increase sensitivity to one-molecular thickness of contaminant.
Atomizer	Surface is cleaned and dried. Water is applied as a spray with an atomizer. The droplet pattern with the advancing contact angle is observed to determine surface cleanliness.	Sensitive but only for hydrophobic soils; results affected by spray time, nozzle-to-part distance, atomizer air pressure and ambient temperature; applicable to small cross-sectional areas with magnification (5X to 40X); not usable with stainless steel or gold. Surface must be smooth and free of wettable detergent films.
Contact angle	A light beam is directed into a water droplet on the test surface. The angle of the reflected beam indicates the contact angle or angle of incidence. Greater contact angles indicate larger amounts of contamination.	Effective only on nonwetting or hydrophobic contaminants.
Ring test	A droplet of water on a surface tension ring tester is repeatedly lowered to contact the test surface. The number of contacts, or B-number, indicates surface cleanliness.	Must be performed by a trained operator to be repeatable; a measure of surface wettability.
Radioactive tracer	A specific quantity and composition of tagged synthetic soil is applied to a test piece. After cleaning, the test piece or cleaning solution is monitored for residual tracer activity.	Primarily a test of cleaning method effectiveness; involves statistical treatment of data; highly sensitive and quantitative test.
	The formula for calculating the soil remaining is as follows: $\frac{\text{Final count}}{\text{Initial count}} \times \frac{\text{mg of initial soil}}{\text{area of test panel}} = \text{soil remaining}$	
Radiochemical	A surface contaminant is dissolved in place by a small amount of radiochemical solution. The change in rate of evaporation of the solution is measured by a Geiber-Müeller tube and is indicative of the soil concentration. A stream of dry nitrogen is passed over the sample to standardize evaporation parameters.	Quantitative results are obtainable if the type of contaminant is known, and calibration curves are constructed and used as standards. Sensitivity and accuracy are sacrificed if the test surface is porous or absorbent. Variables include rate of solution, ambient temperature and pressure, rate of dry nitrogen flow, and latent heat of vaporization of the radiochemical.

TABLE 3-41
(continued)

Name of Test	Test Method	Characteristics or Limitations
Gravimetric	A test piece is weighed before and after cleaning, or the soil remaining from the evaporated cleaning solvent is weighed.	Results show good sensitivity (5×10^{-5} gm/cm^2), but are more indicative of the effectiveness of the cleaning method than surface cleanliness.
Ferrocyanide paper	Paper is immersed in a solution of NaCl, $K_3Fe(CN)_6$, and $K_4Fe(CN)_6$ in water and dried. Paper is moistened and placed on metal surface, then removed and rinsed in clear water. Clear areas on the paper are caused by soil on the metal.	Limited to ferrous metals and laboratory tests.
Copper dip	Cleaned metal panels are dipped in an acid copper sulfate (copper flash) solution.	Adherence, continuity, and appearance of copper flash indicate part cleanliness before the test. Limited to ferrous metals; requires an experienced operator.
Solvent ring	A drop of solvent is repeatedly deposited and picked up from the test surface. It is finally deposited on a quartz or glass slide and dried. If contamination is present, a ring will be formed on the slide.	Enables subsequent identification of soil by infrared spectrophotometry, assumes use of a high purity solvent.
Solvent monitoring	After each cleaning step, used solvent is filtered through membrane filters and examined for levels of particulate contamination. NVR is also monitored. Deionized water rinses are monitored for resistivity if ionic cleaners are used.	Commonly used indirect method which assumes part cleanliness if the solvent no longer removes contamination.
Indium adhesion	The tip of a freshly broken indium rod is forced against the test specimen surface with a force of ~10 grams. The force is maintained for periods of <1 second up to 5 seconds. The rod is then removed from the surface and force-time characteristics are recorded. The coefficient of adhesion (ratio of tensile force to break the bond to the compression force exerted to form the bond) indicates the degree of surface cleanliness.	Adaptable for production testing; a sensitive direct test; coefficient values must be established for different soils and substrates; offers rapid feedback of test data; test surface must be accessible to the indium tip.

TABLE 3-42

Selected ASTM Test Methods

ASTM Designation	Test Title
	Tests for Surface Contamination
F 21-65	Test for Hydrophobic Surface Films by the Atomizer Test
F 22-65	Test for Hydrophobic Surface Films by the Water Break Test
F 24-65	Measuring and Counting Particulate Contamination on Surfaces
F 59-65T	Identification of Metal Particulate Contamination Found in Electronic and Microelectronic Components and Systems Using the Ring Oven Technique, with Spot Tests (tentative)
	Tests for Solvents
F 52-65T	Test for Silting Index of Fluids for Processing Electronic and Microelectronic Devices (tentative)
F 58-65T	Measuring Resistivity of Electronic Grade Solvents (tentative)
F 60-65T	Detection and Enumeration of Microbiological Contaminants in Water Used for Processing Electronic and Microelectronic Devices (tentative)
D 1901-61T	Tests for Relative Evaporation Time of Halogenated Hydrocarbon Solvents and their Admixtures
D 2109-64	Tests for Nonvolatile Matter in Halogenated Organic Solvents and their Admixtures

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SECTION 4

CONTAMINATION CONTROL IN GASES AND LIQUIDS

Controlling contamination in gases and liquids requires methods applicable to the type and quantity of contaminants and the cleanliness level required for a particular application. Gases and liquids may be grouped according to their two major uses:

a. As part of a system, such as hydraulic fluids and actuating or control gases, fuels, coolants, lubricants, and refrigerants.

b. In processing and in support of system operations such as cleaning solvents, flush gases and liquids, cutting oils, and lubricants.

When used as part of a system, the gas or liquid may be recycled or reused often. In such cases, methods for controlling contamination with capabilities for monitoring or verifying the cleanliness level may be designed as part of the system.

Specifications for procurement of gases and liquids should include the required purity level and tolerable concentrations of specific impurities.

Contamination controls should include methods of verifying the purity levels prior to use and monitoring the cleanliness levels periodically during use, to assure that acceptable levels are being maintained.

The storage, transportation, handling, and transfer of gases and liquids should not contribute to their contamination. These operations require well-defined control techniques and practices to maintain the required purity levels.

4.1 Contaminants in Gases

Gases discussed herein are those defined by the U.S. Interstate Commerce Commission as "Compressed or Liquefied" in the interest of safe handling and transportation in interstate commerce. These gases are segregated into the following major groups, as they differ in physical state when contained.

Nonliquefied gases are those which do not liquefy in containers at normal temperatures and under pressures up to 2000 to 2500 psig, normally attained in commercially used containers. However, these gases will liquefy at cryogenic temperatures (approximate range from -200° to -459°F).

Liquefied gases are those which do become liquids, to a very large extent, in containers at or near normal temperatures and under pressures ranging from 25 to 2500 psig, normally attained in commercially used containers.

4.1.1 Description of Gases

Pertinent information on each of the compressed gases is essential to the effective application of a specific gas as part of a system or in processing and in support of system activities. General information is available from the gas producer or distributor. More detailed information is contained in much of the open literature (see Paragraph 4.3, Bibliography). Essential information is provided below:

a. Physical properties include boiling points, critical temperatures and pressures, specific heat, density, and other data for each gas. Table 4-1 lists some of the common gases and their properties. The data given generally represent the properties of a pure gas. Therefore, the values of certain of these properties will vary somewhat with various purity levels. It should also be noted that the factors used in expressing values of properties will vary depending on the source of the data.

b. Formulation includes elements of gas mixtures and impurities, with concentrations of each gaseous element, water, oil, and particulates in each available grade.

c. Materials of construction which are suitable or not suitable for containment of the gas as related to pressure, temperature, and corrosive limitations.

d. Physiological effects are odor, toxicity, threshold limit values, contact irritation to skin, eyes, etc.

e. Precautions in handling and storage include containers, safety devices, temperatures, flammability, etc.

f. Marking and identification of containers include methods of marking, type of data marked on containers, and color marking. These methods may vary with the different producers.

4.1.2 Purity Levels and Grades

Minimum purity levels of gases are normally defined by percent by volume. Maximum impurities are defined by parts per million by volume. Factors for interconversion of the various concentration units are shown in Table 4-2.

Analysis of individual impurities may be automatically supplied with the higher purity grades or may be available on request from the producer.

Terms or nomenclature used by the compressed gas industry to define grades of gases relative to the purity levels vary widely among producers, and often between gases from one producer. A grade term defining a purity level for one gas may define a different purity level for another. Therefore, a single grade term defines a purity

TABLE 4-1

Low Temperature Physical Properties of Gases

Name	Formula	Molecular Weight	Normal Boiling Point			Critical Point		Triple Point or (Melting Point)		Specific Heat Cp @ 70°F, 14.7 PSIA BTU/ (lb. mole) (°F)	Gas Density @70°F 14.7 PSIA lb./cu. ft.
			Temp. °F.	Liquid Density lb./cu. ft.	Latent Heat BTU/ lb.-mole	Temp. °F.	Pressure PSIA	Temp. °F.	Pressure PSIA		
Acetylene	C_2H_2	26.04	—119.2 (3)	38.7 (3)	9180 (3)	96.0	906	—114.6	17.4	10.6	0.0680
Air (1)	(2)	28.96	—317.9	54.56	2556					7.0	0.07493
Ammonia	NH_3	17.03	— 28.1	42.6	10037	270.3	1639	—108.0	8.8×10^{-1}	8.6	0.0445
Argon (1)	A	39.95	—302.6	86.98	2804	—187.6	705	—308.9	9.99	4.98	0.1034
Carbon Dioxide	CO_2	44.01	—109.3 (3)	97.5 (3)	10854 (3)	87.9	1071	— 69.9	75.1	8.95	0.1144
Carbon Monoxide	CO	28.01	—311.9	49.3	2597	—220.4	508	—337.1	2.23	6.97	0.0725
Carbonyl Sulfide	COS	60.07	— 58.3	73.0	7961	221.0	896	(—217.8)		9.92	0.1521
Chlorine	Cl_2	70.91	— 29.3	97.4	8780	291.2	1118	—149.8	2.02×10^{-1}	8.2	0.1853
Deuterium	D_2	4.03	—417.3	10.7	540	—390.8	239	—426.0	2.48	6.97	0.0104
Ethane	C_2H_6	30.07	—127.6	33.8	6315	90.1	708	—297.9	1.20×10^{-4}	12.6	0.0783
Ethylene	C_2H_4	28.05	—154.8	35.2	5826	49.1	735	—272.5	1.70×10^{-2}	10.4	0.0729
Fluorine	F_2	38.00	—306.6	93.8	2815	—200.2	808	(—363.3)		7.49	0.0983
Freon—12	CCl_2F_2	120.92	— 21.6	92.9	8592	233.6	597	(—252.4)		17.66	0.318
Freon—13	$CClF_3$	104.46	—114.6	95.0	6670	83.9	561	(—294.0)		16.09	0.273
Freon—14	CF_4	88.01	—198.4	122.4	5160	— 49.9	542	—299.2	1.70×10^{-2}	14.6	0.228
Freon—22	$CHClF_2$	86.47	— 41.4	88.2	8704	204.8	716	(—256.0)		13.35	0.229
Helium (1)	He	4.00	—452.13	7.798	36	—450.2	33	—455.8 (4)	7.35×10^{-1}(4)	4.98	0.01034
Hydrochloric Acid	HCl	36.46	—120.9	74.3	6948	124.5	1199	(—173.)		6.9	0.0950
Hydrogen (1)	H_2	2.02	—422.99	4.418	389	—399.8	188	—434.5	1.044	6.89	0.005209
Hydrogen Sulfide	H_2S	34.08	— 75.4	60.0	8033	212.7	1307	—122.0	3.36	8.2	0.0892
Krypton (1)	Kr	83.80	—244.0	150.6	3884	— 82.8	796	—250.9	10.62	4.98	0.2172
Methane	CH_4	16.04	—258.6	26.5	3519	—116.6	670	—296.5	1.69	8.6	0.0416
Methyl Chloride	CH_3Cl	50.49	— 11.5	62.2	9293	289.6	967	—144.0	1.27	9.97	0.133
Neon (1)	Ne	20.18	—410.7	75.35	748	—379.7	395	—415.4	6.27	4.98	0.05215
Nitric Oxide	NO	30.01	—241.0	79.3	5953	—137.2	945	—263.6	3.16	7.1	0.0777
Nitrogen (1)	N_2	28.01	—320.5	50.46	2405	—232.6	491	—345.9	1.82	6.98	0.07245
Nitrogen Trifluoride	NF_3	71.01	—199.2	96.0	4984	— 38.7	657	(—343.3)	1.77×10^{-6}		0.1864
Nitrous Oxide	N_2O	44.01	—127.2	76.8	7110	97.7	1054	—131.6	12.74	9.2	0.1146
Oxygen (1)	O_2	32.00	—297.3	71.27	2932	—181.1	737	—361.8	2.10×10^{-2}	7.02	0.08281
Ozone	O_3	48.00	—169.4	101.8	6174	10.2	791	(—314.5)			0.124
Propane	C_3H_8	44.10	— 43.7	36.2	8076	206.2	617	—305.8	8.39×10^{11}	17.4	0.1154
Propylene	C_3H_6	42.08	— 53.8	37.5	7925	197.4	667	—301.0	2.44×10^{-8}	15.3	0.1070
Sulfur Dioxide	SO_2	64.06	13.9	89.3	10728	315.0	1142	—103.8	2.43×10^{-1}	9.6	0.1687
Xenon (1)	Xe	131.30	—163.0	190.8	5436	61.9	847	—169.2	11.82	4.98	0.3416

(1) Based on data from the Compressed Gas Association Meeting June 19, 1962

(2) Proximate composition of dry air (Mole Percent): 78.09 N_2, 20.95 O_2, 0.93 Ar, 0.03 CO_2

(3) Denotes sublimation and solid density

(4) λ (lambda) point

TABLE 4-2

Factors for Interconversion of Concentration Units of Gases and Vapors

Desired Units ↓ / Present Units →	Percent by Volume	Parts per Million by Volume	Moles per Liter	Milligrams per Cubic Centimeter	Milligrams per Liter	Milligrams per Cubic Meter	Milligrams per Cubic Foot
Percent by volume	-	10^{-4}	2450	24,500/M	2.45/M	2.45×10^{-3}/M	0.0863/M
Parts per million by volume	10^{4}	-	24.5×10^{6}	24.5×10^{6}/M	24,500/M	24.5/M	863/M
Moles per liter	4.1×10^{-4}	4.1×10^{-8}	-	1/M	10^{-3}/M	10^{-6}/M	35.3×10^{-6}/M
Milligrams per cubic centimeter . . .	$4.1\ M \times 10^{-4}$	$4.1\ M \times 10^{-8}$	M	-	10^{-3}	10^{-6}	35.3×10^{-6}
Milligrams per liter	0.41 M	$4.1\ M \times 10^{-5}$	$M \times 10^{3}$	10^{3}	-	10^{-3}	0.0353
Milligrams per cubic meter	410 M	0.041 M	$M \times 10^{6}$	10^{6}	10^{3}	-	35.3
Milligrams per cubic foot	11.6 M	$1.16\ M \times 10^{-3}$	28,300 M	28,300	28.3	0.0283	-

How to use table:

1. Locate column along top of table which gives present unit.
2. Locate row along left of table which gives desired unit.
3. Read down and across to locate multiplying factor.
4. Multiply present quantity by factor.

Example: Given 700 ppm to convert to moles per liter:
$700 \times 4.1 \times 10^{-8} = 2.87 \times 10^{-5}$ moles/liter.

Note: In table, M is molecular weight of the gas or vapor.

level of a single gas from a single producer. The same grade term may define a different purity level when used by other producers. Some of the most commonly used terms for gas grades are listed below in alphabetic order and do not imply any relative order of purity.

Grades	
Analytical	Research
Commercial	Technical
High purity	Ultrapure
Instrument	Zero
Prepurified	

Impurities found in various gases may be generally classified as gaseous and aerosol (liquid and solid particulates). Gaseous impurities are principally small concentrations of the constituents of gaseous or liquid media from which the basic gas is extracted or from other substances used in production processes.

In some gases forms of hydrocarbons may be an intolerable element. Sources of hydrocarbons when not a normal element are residues of cleaning solvents from containers and system equipment, and from lubricants used in processing equipment and containment systems.

Water in either liquid or vapor form is usually a major significant containment in all gases. The water content of a gas is usually reduced to an extremely low level by the normal gas production processes. However, additional amounts of water are easily introduced into the gas from the air both by inboard leakage into the system and during transfer to a container or from a container to the user's system. Another source of water is inadequately dried containers, transfer equipment, and materials and equipment used in gas systems.

Oils in liquid or vapor form may be introduced into the gas from lubricants and packing materials or sealants and inadequately cleaned equipment used in the production processes and the containment system.

Solid particulates are not normally found in any significant volume in newly produced and purified gases. Principle sources of particulates are corrosion, rust, scaling, and flaking of containers used to transport the gas or to contain the gas in the user's system. For this reason, gas producers are reluctant to certify any maximum concentration of particulate matter in gases.

Table 4-3 is a list of some commonly used gases with typical minimum purity levels that exist in the higher purity grades available from most producers. The impurities, which are those normally found, are given with the maximum values for each, and are typical of the concentrations that may be expected for the designated purity level. Actual analysis will vary with each batch or container of a specific gas and may reveal some impurities not shown.

Producers in the compressed gas industry with highly developed, well-controlled processes for separation and purification are capable of providing gases of extremely high purity levels which meet most use requirements. Research and development in this field are constantly refining these processes to a point where some impurities can be

TABLE 4-3

Typical Purity Levels and Impurity Concentrations of Gases

NAME	(a) PURITY LEVEL % VOLUME	(b) IMPURITIES IN PPM													
		Acetylene (C_2H_2)	Argon (Ar)	Carbon Dioxide (CO_2)	Carbon Monoxide (CO)	Helium (He)	Hydrogen (H_2)	Krypton (Kr)	Methane (CH_4)	Neon (Ne)	Nitrogen (N_2)	Nitrous Oxide (N_2O)	Oxygen (O_2)	Xenon (Xe)	Water (H_2O)
Argon	99.999	0.05	-	0.5	1.0	5.0	1.0	-	0.5	-	3.0	0.1	1.0	-	1.0
Helium	99.9995	0.05	-	0.5	1.0	-	1.0	-	0.5	2.0	5.0	0.1	1.0	-	1.0
Hydrogen	99.999	0.05	5.0	0.5	1.0	5.0	-	-	0.5	-	5.0	0.1	1.0	-	1.0
Krypton	99.99	0.5	-	0.5	10.0	5.0	1.0	-	5.0	50.0	25.0	0.1	2.0	25.0	1.0
Neon	99.998	0.5	-	0.5	1.0	25.0	1.0	-	0.5	-	5.0	0.1	1.0	-	1.0
Nitrogen	99.999	0.05	5.0	0.5	1.0	5.0	1.0	-	0.5	-	-	0.1	1.0	-	1.0
Oxygen	99.995	0.05	5.0	0.5	1.0	5.0	5.0	5.0	0.5	5.0	15.0	0.1	-	-	1.0
Xenon	99.99	0.5	-	5.0	10.0	5.0	1.0	25.0	5.0	5.0	5.0	0.1	5.0	-	1.0

(a) Purity levels may be equal to or greater than (≥) the values shown.

(b) Impurity concentrations may be equal to or less than (≤) the values shown.

reduced to a virtually undetectable level. The major problem, then, is maintaining the gas purity level in containers and containment systems to the ultimate use point. Initial potential sources of impurities in gases are producer storage containers, transfer equipment, shipping containers, and handling practices.

It may be reasonable to assume that a container of gas is of that purity level labeled or certified by the producer. However, when the use requirements are critical, a complete and accurate analysis by a qualified laboratory may be needed.

4.1.3 Gas Systems

The gas user is responsible for maintaining or purifying a gas within the cleanliness level compatible with end use requirements. Gases which do not meet needed purity levels may require extensive purification facilities, which are not economically feasible except for the high volume user. Hence, the most economical gas for the lower volume user is one obtained within the required purity level. Techniques for contamination control in this paragraph are limited to the user gas system.

A gas system used for the containment, control, and distribution of a compressed gas includes the following components:

Tanks	Tubing
Fittings	Nozzles
Regulators	O-rings and packing
Valves	Filters and other purification equipment

The assemblage of the above parts and components in a system constitutes the principal source of contaminants to the gas. Types of contaminants, examples of each, and some of the principal sources are shown in Table 4-4.

Effective contamination controls must be considered in the design stage of a gas system and implemented throughout the assembly operations. (See Section 2 for product design considerations.) In addition to general design considerations, some characteristics unique to a gas system that should be considered are given below:

a. All materials exposed to the gas should not be adversely effected by the particular gas.

b. Parts and equipment such as regulators, valves, flow meters, safety devices, tubing, etc., should have a minimum of entrapment areas and should be suitable for the pressures involved.

c. For oxygen systems, eliminate sharp bends in parts and system configuration to prevent erosion, hot spots, and ignition; and provide special conditioning procedures to assure removal and exclusion of all combustible substances.

d. Seals or packing and lubricants in operating parts should be minimum contributors of contaminants to the gas system.

e. Cleaning agents should be minimum contributors of contamination and easily removed from the system.

f. Provide procedures and equipment to prevent contaminants from entering the system when it is opened for any reason.

g. After system cleaning a final rinse, flush or purge should be used to assure removal of cleaning agents and residue (e.g., removal of hydrocarbons by steam flushing and water by heating, dry gas purging, and evacuating).

TABLE 4-4

Contaminants in Gas Systems

Types	Examples and Sources
Gases and vapors (Adsorbed on surfaces or otherwise trapped or generated within the system)	Vapors from cleaning solvents Vapors from assembly process materials Atmospheric air Products from chemical reactions of materials in the system with cleaning agents, process materials, atmospheric air, etc.
Particulates (Solid and liquid droplets)	Residue from cleaning agents and processes Residue from assembly processes and materials Condensates from air, gases, and vapors by temperature and pressure changes Airborne particles Wear particles from valves, regulators, and other equipment operated in the system Corrosion products generated in the system

The following factors should be considered in determining requirements for gas purification equipment:

a. Specified purity level for end use

b. Purity levels available from the producers

c. Specific contaminants or impurities in gases as received that must be removed or reduced in concentration

d. Economics involved--e. g., cost of producer delivering gas of the required purity level versus cost of design, installation, and maintenance of purification equipment

e. Capabilities of purification equipment to remove specific impurities to the levels required

f. Types and concentrations of contaminants introduced by the gas system.

The principal contaminants present in gases as procured and those introduced by a gas system are:

a. Particulates such as corrosion products, rust, scale, wear products, shedding, and flaking of materials from shipping containers and from the gas system

b. The water content of most gases can normally be reduced to an acceptable maximum concentration by the producer. Inboard leakage of the ambient atmosphere into gas systems is a primary source of moisture. Inadequately dried containers and systems and particulate filter equipment are other sources.

Equipment for use in-line with a gas system to remove the principal contaminants, as well as special design equipment, is available from gas equipment companies.

a. Selection and design of particulate filters should consider compatibility with the gas, flow rate, pressure, and temperatures involved. Special consideration should be given to the filter media with regard to:

   (1) removal rating

   (2) working pressure

   (3) material

   (4) migration or unloading

   (5) water-vapor and oil-vapor content

   (6) other characteristics that may contribute contaminants to the system.

   In-line filters are usually located at the point of egress from shipping container or point of ingress to the gas system, or both if the transfer equipment and line are extensive, to exclude particulates from the system, or at or near the point of gas usage to remove particulates to an acceptable level for final use.

b. Some adsorptive materials used in drying equipment (for water vapor removal) may have a water content in excess of that in the gas, resulting in an increase of water content rather than the intended decrease.

   Molecular sieves that have been adequately dehydrated are very effective media for drying gas to low levels of water content.

   Drying equipment should be located as near as possible to the point of gas usage to preclude additional moisture being introduced between the dryer and point of use.

c. Other purification equipment employing various methods of absorption, adsorption, phase separation, and chemical catalysis may be used in removing or reducing gaseous impurities. Most of these processes require highly specialized techniques and complex equipment, which are not normally economically feasible for a low volume user.

4.1.4 Specifications and Analysis of Gases

The needed cleanliness level or purity of a gas used as part of a system or process is determined by the cleanliness level requirements of the specific application. To facilitate this determination and to formulate a gas specification that will adequately describe the requirements, the following factors should be considered:

a. Chemical and physical properties of the gas as they may affect usage requirements

b. Normal impurities in the gas as they may affect usage requirements

c. Purity levels with concentrations of impurities of the gas normally supplied by producers

d. Cautions and hazards in handling, containment, and use of the gas

e. Facilities and methods required for monitoring or verifying purity levels or concentrations of specific contaminants

f. Facilities required for the removal of specific contaminants

g. Contamination potential of the gas containment or distribution system.

A procurement specification for a gas should adequately describe the acceptable purity level and impurity concentrations in terms such as the following (see Table 4-3):

a. Gas purity level--specify minimum percent by volume

b. Normal gas impurities--specify allowable maximum concentration by parts per million or percent by volume

c. Water content--specify allowable maximum concentration by dew point ($^{\circ}$F or $^{\circ}$C) or parts per million

d. Other gaseous impurities that must be limited--specify allowable maximum concentration by parts per million or percent by volume

e. Particulate matter (fiber and nonfiber)--specify allowable maximum particle sizes with maximum allowable number per unit volume

f. Particulate matter (viable)--specify allowable maximum limits. (See Section 6 on microbial contamination and control.)

Gas analysis is the identification and/or quantitative measurement of gas constituents. These analytical measurements are significant to the producer and user. When applied, the measurements:

a. Provide a check on production processes and controls

b. Determine quality of end product

c. Provide a comparison with specifications

d. Detect trace impurities and contaminants

e. Provide continuous analysis or monitoring for compatibility with use requirements.

All analytical methods and techniques are fundamentally based on the interactions between matter and energy. Energy states, characteristic of the composition of any particular substance, are readily inferred by observing the consequences of interaction between the substance and an external source of energy. External energy sources may be grouped according to their basic modes of interaction with matter. A variety of analytical techniques and instrumentation is available depending on the type of energy, the means of using the energy, and the elements to be measured. Some of the techniques for gas analysis for each mode of energy used are shown in Table 4-5.

Methods for completely analyzing a specific gas may employ a variety of physical and chemical techniques and instrumentation, in different combinations, to provide identification and measurement of all constituents. The basic steps of analysis for a practical application consist of:

a. Obtaining a true representative sample of the gas stream

b. Separating the sample into its components or constituents or identifying those constituents of analytical interest

c. Determining the quantity of each constituent with relation to the whole sample or to one another

d. Recording the analysis results.

TABLE 4-5

Analysis Techniques for Gases

Techniques	Type Interaction	Definition	Energy Used
Ultraviolet spectrophotometry	Transmission and reflection	Measurement of the quantity and quality of electromagnetic radiation emitted, reflected, transmitted, or diffracted by the sample	Electromagnetic radiation
Light scattering			
Infrared spectrophotometry			
Microwave spectroscopy			
Orsat analyzer	Consumption of sample or reactant	Measurement of results in terms of amount of sample or reactant consumed, product formed, thermal energy liberated, or equilibrium attained	Reaction with other chemicals
Automatic titrators			
Impregnated tape	Measurement of reaction products		
Photometry			
Colorimetry			
Gas chromatography			
Combustion	Thermal energy liberation		
Other thermic reaction			
Mass spectroscopy Nier type Omegatron Time of flight	Ion separation	Measurement of the current, voltage, or flux changes produced in energized electrical and magnetic circuits containing the sample	Electrical and magnetic fields
Gaseous conduction	Electrical properties		
Paramagnetism	Magnetic properties		
Nuclear magnetic resonance			
Conductivity	Thermal	Measurement of results of applying thermal or mechanical energy to a system in terms of energy transmission, work done, or physical state	Thermal or mechanical energy
Dew point			
Sound velocity	Mechanical		

suspended in the gas are usually limited to these applications. However, in selecting this type specifically for moisture or particulate analysis, consideration must be given to other elements in the gas that will interfere with the instrument sensitivity.

Moisture monitoring instruments and techniques must be capable of measurements within the range of concentrations expected and the limits required. Other elements of the gas should not interfere or affect the sensitivity of the instrument. The adaptability to continuous and automated analysis should be considered if this is a requirement. Some of the instruments or techniques for humidity or water-vapor analysis are: (a) dew point -- other corrosive gases and vapors having dew points relatively close will cause errors; (b) electrical conductivity -- sample flow must be low, may be affected by other vapors, and corrosive or water soluble gases; (c) hygrometers -- affected by contaminants absorbed on wet-bulb wick (mechanical hygrometers are also available); and (d) volumetric absorption (pneumatic bridge).

Instruments and techniques for determining sizes and quantity of particulates suspended in the gas must have measurement capabilities within the ranges required. Two of the instruments and techniques are the light-scattering photometer which determines particle size or concentration level, and the microscopic measurement which consists of collecting the sample on a filter media for measurement; usually a grab sample technique.

4.1.5 Safe Handling of Compressed Gases

Compressed gas users should comply with all applicable regulatory standards in the use, handling, and storage of compressed gases. Regulatory standards include:

a. ICC regulations on the transportation of explosives and other dangerous articles

b. FAA regulations on the transportation of compressed gases by air

c. U.S. Coast Guard regulations on the transportation of compressed gases by water

d. ASME code on pressure vessels

e. ASME code on pressure piping

f. Compressed Gas Association standards

g. Local, state, and municipal codes and standards applicable to the use and storage of compressed gases.

These standards are considered minimum requirements. Supplemental procedures for the safety of operational personnel and the protection of equipment and facilities must be compatible with these minimum requirements, and should include such other procedures that are required for a particular operation or gas usage.

The selection of methods and instrumental techniques for gas analysis involves consideration of a number of factors. The factors include:

a. How the techniques will be employed:

(1) laboratory analysis

(2) continuous analysis (automated).

b. Knowledge of the probable composition of the sample:

(1) a knowledge of the constituents of analytical interest permits selection of instrumentation for a quantitive measurement of each known element

(2) identification of unknown elements requires instrumentation for both identification and quantitive measurement.

c. The physical state of the gas, which is normally gaseous. However, some constituents or impurities may be in other states such as:

(1) particulates--solid

(2) moisture or water--liquid.

d. Instrument performance which includes the following:

(1) <u>sensitivity</u> -- the smallest change that can be reliably detected and distinguished from background noise or drift

(2) <u>range</u> -- the span of concentrations of which the instrument is capable of measuring

(3) <u>accuracy</u> -- the accuracy of instrument readings with respect to the actual value being measured

(4) <u>temperature effects</u> -- ambient temperature effects on instrument and requirements to compensate for temperature of sample.

The selection of methods and instrumentation for a complete analysis instrument must be tailored to the sample composition and the information requirements. Some techniques are rather universal, permitting identification and measurement of most constituents. These are known as specific type techniques and are usually more complex and costly, and sometimes less sensitive. The less specific types are usually simpler but are less able to distinguish between related substances having similar interactions with energy. The nonspecific instruments usually have greater sensitivity to extremely small concentrations of the element being measured and are usually more adaptable to continuous analysis operations and automation. Instruments and techniques used to measure concentrations of water vapor or moisture and to size and count particulates

c. Absorbed gases

d. Particulate matter

e. Microbial matter (viable particulates).

These contaminants normally originate from the following sources:

a. May be contained in the liquid as received from the producer

b. May be generated by use in cleaning processes or system operation

c. May be contributed by storage tanks, pipes, valves, and other system components

d. May be contributed by exposure to ambient air (particularly high-purity water).

The effects of contaminants in liquids are similar to the effects of the same contaminants in any other environment. However, the method of migration is different, and the contaminant may in some cases assume different forms. A representative list of the effects of contaminants in liquids is shown in Table 4-6.

TABLE 4-6

Effects of Contaminants in Liquids

Contaminant	Effects
Nonvolatile residue	Contact resistance Increased wear Corrosion Noncompatible with LOX systems
Particulate	Increased friction, wear, and erosion Mechanical restriction Electrical malfunction Photographic process degradation Corrosion
Microbial	Deterioration of material Cross infection Creation of nonsterile conditions Water and food pollution Purity dilution of pharmaceutical products
Other liquids	Dilution; reduced effectiveness Corrosion Chemical reactions; acidity, safety hazards

Compressed gases, like high explosives, are a form of stored energy and are potentially hazardous. Strict compliance with safe-handling practices, procedures, and standards by all personnel involved will ensure control of all potential hazards and incidents.

Five basic practices interdependent in achieving a high degree of safety in a compressed gas system are:

a. Engineering design compatible with pressure, volume, and particular gas used

b. Assembly practices and processes with good quality control

c. Proper assembly in accordance with design specifications

d. Proper operation in accordance with safe practices

e. Adequate maintenance and inspection to assure continued safety.

Compressed gas containers most commonly encountered by the user are cylinders. Rules and regulations pertaining to cylinders apply equally to spheres and drums where their alternate use is authorized by ICC regulations. Cylinder safety begins with the supplier by his adherence to ICC regulations covering:

a. Inspection and testing

b. Proper filling

c. Valves

d. Safety relief devices

e. Marking and labeling

f. Transportation.

4.2 Contaminants in Liquids

In rough cleaning operations, contamination in the cleaning solution may be a normal condition. In precision cleaning, however, the contaminant level is of definite concern and should be monitored periodically to assure that the required purity level is maintained. Contaminants in liquids consist of five primary types:

a. Nonvolatile residue

b. Other liquids in suspension or solution

TABLE 4-7

Sources and Effects of Contaminants in Hydraulic Systems

Types	Sources	Effects
Dirt and dust	Area of operation of the system Environment of components before assembly or during assembly During manufacture of the components, such as core sand in castings	Wear by abrasion Wear by erosion Obstructs passages Activating force of valves and servomechanisms may be increased or erratic Acts as a chemical catalyst to promote oxidation of the hydraulic fluid
Water	Condensate resulting from low operating temperatures Introduced with fluid used in the system Improper drying of system after cleaning Enters through seals immersed in water or high-humidity environments	Oxidizes some metals used in hydraulic systems Accelerates oil oxidation with a metal catalyst present
Metal particles	Generated during manufacturing of components Generated during assembly of the system Generated during operation of the system	Similar to dirt and dust
Rust	Improper use of carbon steel in the system Flash rust formed during cleaning of carbon steel parts	Similar to dirt and dust
Hydrocarbons Oil oxidation	Presence of air with the hydraulic fluid Accelerated by high temperatures Accelerated by presence of fine particles Accelerated by presence of water	Similar to dirt and dust
Polymerization	Generated by high temperatures Accelerated by presence of fine particles Accelerated by presence of water	Similar to dirt and dust Increases viscosity to change forces required for the system
Sheaves (crystal-like growths)	Formed in presence of Buna-N rubber, oil, and metal High temperatures accelerate the reaction Still fluid accelerates the reaction	Similar to dirt and dust Generation of sheaves may etch away metal even between close tolerance parts such as pistons and cylinder walls
Miscellaneous contaminants	Parts packing material Paint on inside of pipe Surface coatings from improper preparation and cleaning before assembly	Similar to dirt and dust

4.2.1 Hydraulic Systems

The performance of hydraulic systems is directly related to the level of contamination within the system. Contaminants may induce wear on critical components, affect the forces necessary to drive valves or servomechanisms, and directly obstruct hydraulic lines.

An effective method of contaminant removal can be designed only when the types and effects of contaminants have been identified. Some sources and effects of significant types of contaminants are shown in Table 4-7.

a. Design Considerations for a Hydraulic Filtration System -- The life of systems whose accuracy or reliability does not warrant recirculating fluid filtration may be extended by careful cleaning and periodic fluid changes. The cleaning techniques used for components in the system (ultrasonics, vapor degreasing, chemical, etc.) are covered in Section 3 of this handbook. In assembled systems, a cleaning procedure may consist of flushing the lines with a cleaning solution, rinsing with deionized water, and drying with nitrogen. This procedure, however, is only typical; various steps may need to be added or repeated.

   When a hydraulic system requires a recirculating liquid filter assembly, the following factors should be considered in the system design:

   (1) level of contamination permitted

   (2) type and amount of contaminants present

   (3) available space

   (4) volume and type of liquid to be filtered

   (5) type of service and conditions of operation

   (6) adaptability of the unit for adding auxiliary equipment.

b. Design Considerations for a Cleanable Hydraulic System -- In the design and assembly of hydraulic systems, several basic, but sometimes overlooked, factors should be considered in constructing a system that can be cleaned to the tolerances specified. These factors are as follows:

   (1) the materials of construction must be such to permit cleaning to the level required with the cleaning materials and processes needed

   (2) the materials should be identified as to composition

   (3) the materials should be compatible with the liquid used in the system

(4) welds should be placed so as to be cleanable if at all possible

(5) welds should be checked for impurities (scale, spatter)

(6) drain and bleed-out ports should be provided for ease in cleaning

(7) the system should not contain dead end plumbing

(8) the components should be cleaned before assembly

(9) the system should be assembled in a clean area, if possible.

c. Liquid Filtration -- Several types of particle separators are used with hydraulic systems such as gravity settling and centrifugation. However, the main method of separating particles from liquid is filtration. Two major types of filters are surface and depth, and a combination of the two may be used in recirculating hydraulic systems.

Surface filters remove solid particulate matter from liquids by a straining action which does not absolutely filter soluble contaminants and fine particles. The different types and uses of surface filters are described below:

(1) Extended area membrane-type filters are made from paper folded into an accordion pleat and enclosed within a housing. Consequently, this type of filter has a large surface area. By changing the density of the paper and the density of packing, particles of various size ranges can be removed.

(2) Bag filters are made from reinforced cloth in a configuration suitable for insertion in a housing. The filter characteristics are similar to (1).

(3) Wire screens, perforated metal, and discs of pressed sintered powdered metal are generally used to filter gross particulate contaminants and as support for other types of filter material.

(4) Magnetic fields may be used to separate magnetic materials from liquids.

Depth filters allow the liquid to pass through a filter medium. Absorbent and adsorbent filtering action are used in different types of depth filters.

(1) Absorbent filters use materials such as cotton, felt, paper, and hair. Filtration is accomplished as particles are trapped in the filter media. These types of

filters are inactive chemically and remove only solid particles.

(2) Adsorbent filters use materials such as charcoal, bone-black, and clay. This filter adsorbs some dissolved contaminants as well as removes particles by trapping. Adsorbent filters are, however, water-sensitive and must be used only where the system can be kept water-free.

(3) Combination filters can employ most of the above filter types to achieve a combination of filter effects.

d. Contaminant Measurement Methods -- Water-vapor content of an empty system can be measured directly by using standard dew-point measurement techniques on the air in the system.

The general method for measuring particulate contamination is to collect a sample of fluid from the hydraulic system, filter it through a membrane filter, and count and size the particles.* Individual components can be installed in special test systems to test for contaminants in the part or generated by the part. The components may be submersed in ultrasonic tanks to simulate the worst case of particle contamination due to vibration of the component. The Dual Volume sampling method is useful for reducing background count in these types of tests.** In taking samples, many precautions must be taken to avoid particle generation and inaccurate test results.†

4.2.2 Analysis of Contaminants in Liquids

Some of the contaminants found in liquids and particularly those contributed by the system are discussed in Paragraph 4.2.1, Hydraulic Systems. See Paragraph 6.3.2, Monitoring Methods for Microbial Contamination - Liquids, for the microbial detection methods.

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*Procedure for the Determination of Particulate Contamination of Hydraulic Fluids by the Particle Count Method, Society of Automotive Engineers, Inc., ARP 598, March 1, 1960.

**A Method for Determining the Degree of Cleanliness of the Interior of Hydraulic Components and of the Downstream Side of Hydraulic Filter Elements, Field Service Report No. 4, APM-FSR-4A, Aircraft Porous Media, Inc., Glen Cove, N.Y., January 24, 1958.

†A Systematic Approach to Obtaining Meaningful Contamination Data from System Fluid Samples, Field Service Report No. 24, APM-FSR-24A, Aircraft Porous Media, Inc., Glen Cove, N.Y., September 30, 1964.

Liquid dilution by unwanted constituents will not be discussed in detail in this handbook, since this is a matter that can be regulated to a large degree by using definitive specifications in either purchasing or formulating a liquid solution. Periodic chemical analysis is required to assure that prescribed quality levels are maintained. Such analysis may be necessary during and after formulation by the manufacturer, as an acceptance procedure by the user, and periodically during use.

Particulates and other nonvolatile residue present the other greatest concern in contamination control. Gross particulate matter can be seen visually, and smaller particles can be detected by the use of membrane filters and microscopes. One method for detecting particles 5 microns and larger is described in Aerospace Recommended Practice (ARP) 598. A more quantitative method is generally required, however, for most contamination control work. This is described in the following discussion of nonvolatile residue.

Nonvolatile residue (NVR) is defined as the soluble (or suspended) material and insoluble particulate matter remaining after temperature-controlled evaporation of a filtered volatile liquid. The amount of NVR content in solvents must be controlled in cleaning processes in order to obtain desired cleanliness of the product since the NVR will remain on the product after the solvent evaporates. The final rinse stage of any precision cleaning process must utilize only solvent with an extremely low NVR content. Earlier stages in a multistage cleaning operation may be less critical in the control of NVR.

Some typical contaminants encountered in NVR control are:

Skin oils
Solder fluxes
Cutting fluids
Plasticizers
Cleaning solvents
Lubricants.

The primary methods of NVR detection are:

Gravimetric
Nephelometer
Solvent purity meter
Chromatography
Spectrophotometry.

Figures 4-1 through 4-5 depict the apparatus and steps involved in each NVR detection method. These methods are described and compared in Table 4-8.

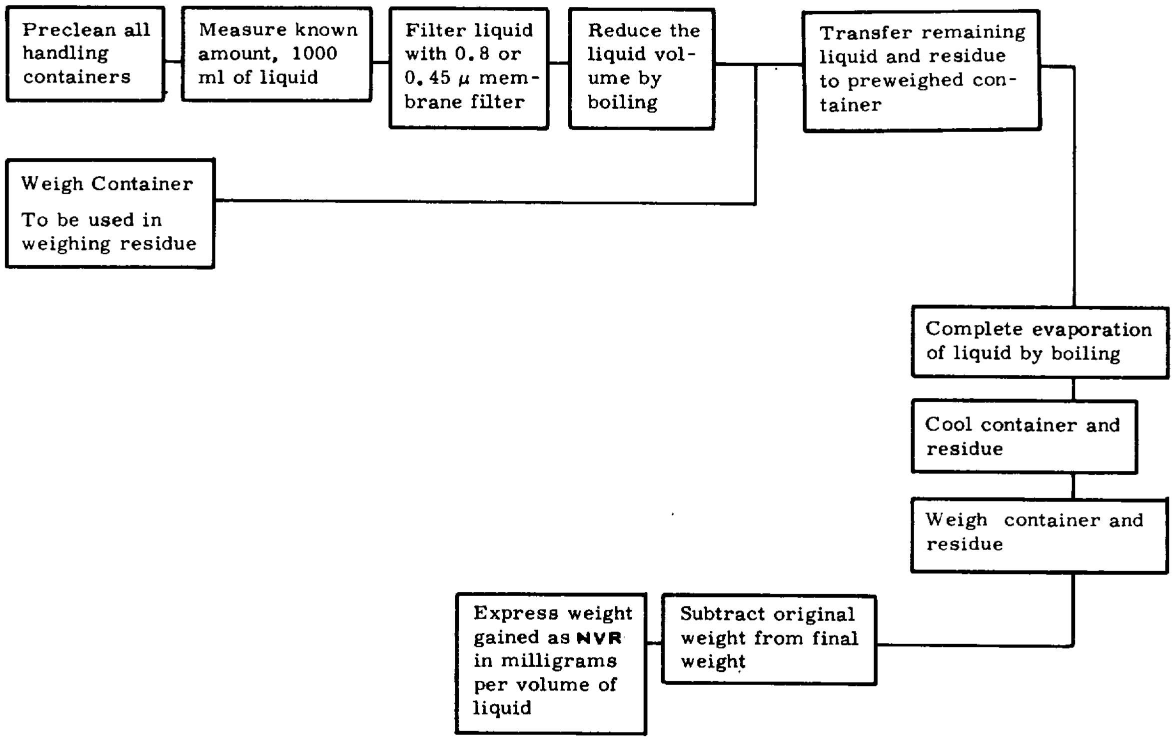


Figure 4-1. Typical gravimetric flow diagram

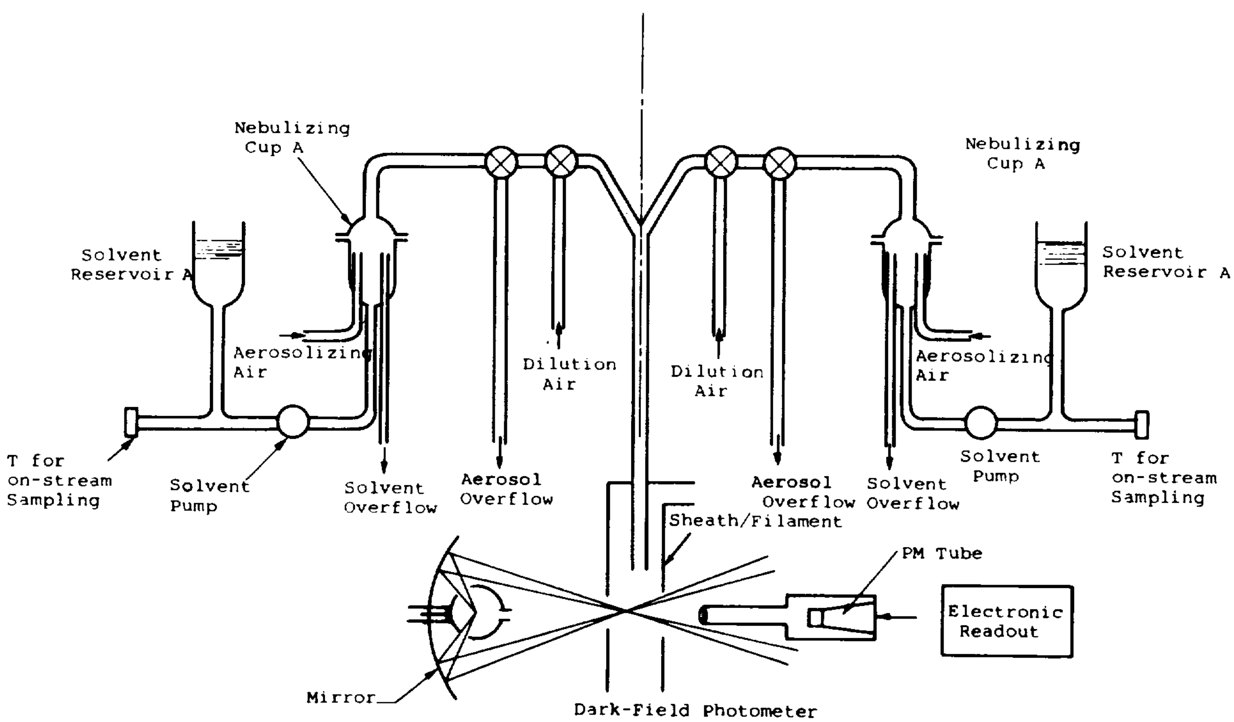


Figure 4-2. Schematic layout of NVR nephelometer

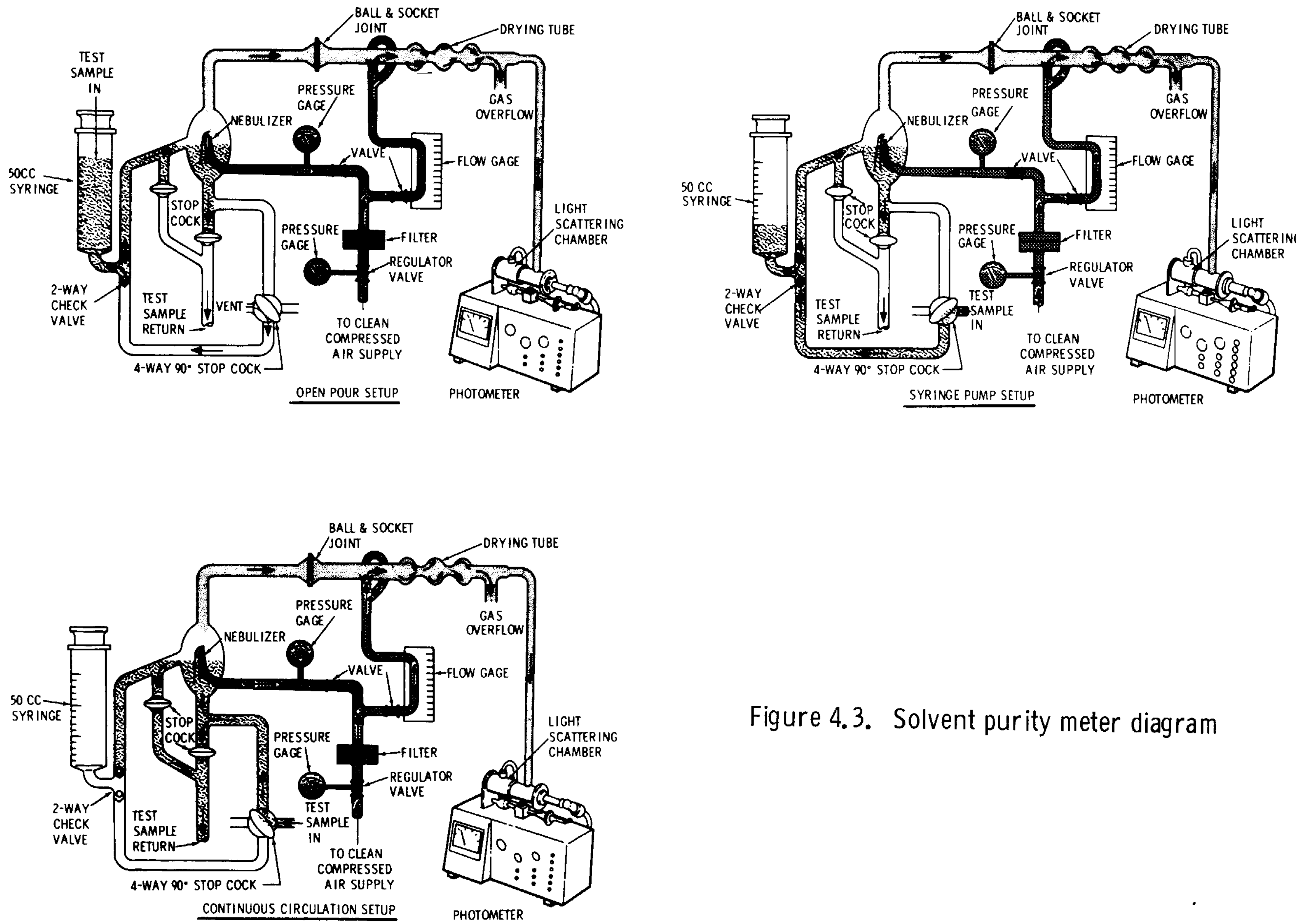


Figure 4.3. Solvent purity meter diagram

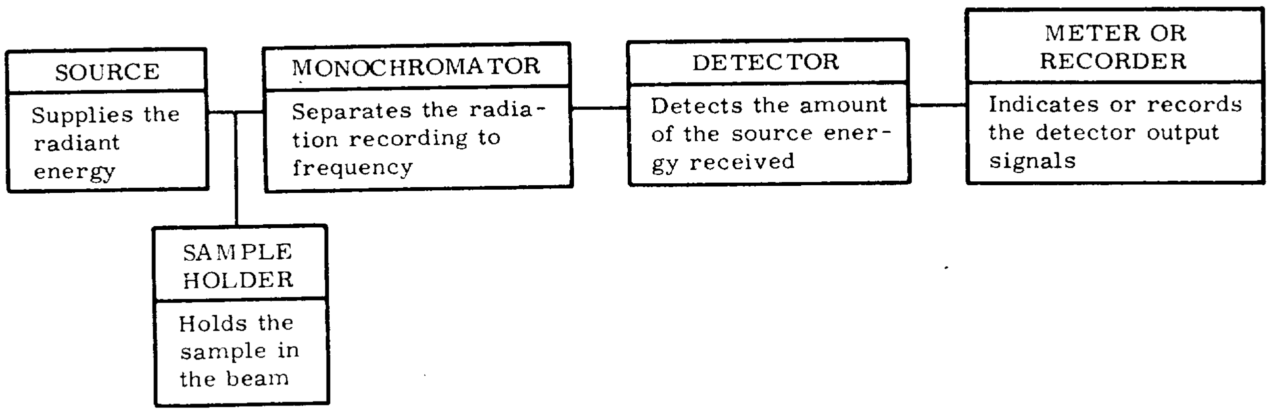


Figure 4-4. Block diagram of typical spectrophotometer

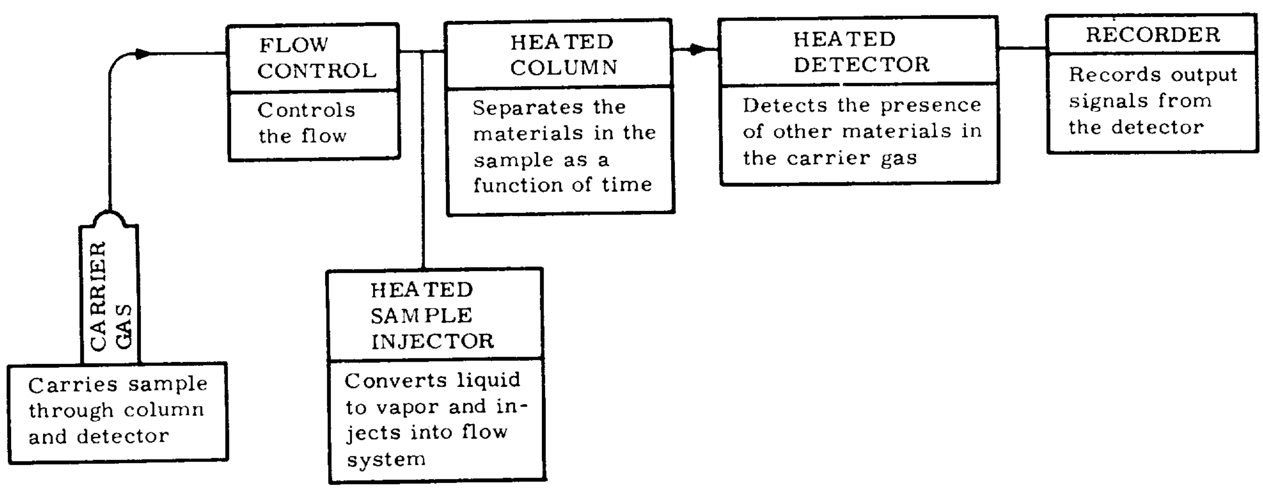


Figure 4-5. Block diagram of typical apparatus for NVR chromatography

Chromatography is a method of separating the constituents of a mixture based on their differences in solubility and mobility through a packed column. The time required for each component to travel through the packed column and appear as a peak on the recording trace is its retention time. Under controlled conditions, each component will exhibit a definite retention time, and this time provides significant information to its identity.

TABLE 4-8

NVR Detection Techniques

Comparison Characteristic	Gravimetric	Nephelometer	Solvent Purity Meter	Spectrophotometry	Chromatography
Principles of operation	Performed by weighing a container and evaporating (by boiling) a known amount of solvent and reweighing the container. The weight gain is NVR.	Solvent is aerosolized by clean air and sampled by forward light-scattering photometer. As NVR content is increased, the rate of evaporation is decreased resulting in larger droplets at the point of scattering, which produces larger signal output of the photometer	Same as nephelometer	Absorption of electromagnetic radiation	Multitheoretical plate Distillation Selective adsorption
Sensitivity	~0.01 ppm by weight	1 ppm	1 ppm	Varies from solvent to solvent; ~1 ppm optimized	1 ppm
Time for determination	May vary from 0.75 to 8.0 hours	~5 minutes	1 minute	5 minutes to 1 hour	5 minutes to 1 hour
Units of measurement	Milligrams per volume, and may be converted to ppm by weight	ppm either by weight or by volume after converting photometer reading by use of calibration curves	ppm either by weight or by volume after converting photometer reading by use of calibration curves	Percent transmittance converted to ppm or actual weight	Retention volume and direct readout are difficult
Operator aspect	Well versed in laboratory techniques, contamination control practices, and precise measurements	On development models was found simple to operate but somewhat difficult to maintain	Extremely simple to operate. Production personnel operate with no difficulty	Comprehensive knowledge of chemistry required for setup and interpretation	Comprehensive knowledge of chemistry required for setup and interpretation
General information	Widely used, recognized by ASTM Standards, may be costly in time and labor. Batch sampling only	Developed by IITRI for NASA. Shows great promise. Batch or continuous sampling	Developed by Sandia and is being marketed by commercial firms. Batch or continuous sampling	Can be quite expensive. Quite specific in application.	May be somewhat limited in identifying the variety of contaminants in a residue

Specifications and tests for NVR follow:

ASTM-NVR-66, Tentative Method of Test for Nonvolatile Residue of Halogenated Solvent Extract from Aerospace Components (Using Rotary Flash Evaporator)

MSFC-QUAL-AMC-5, Analysis of Liquid Samples for Nonvolatile Residue

MSFC-SPEC-164, Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems, Specifications for

MSFC-PROC-195, Cleanliness Level Requirements and Inspection Methods for Determining Cleanliness Level of Gas Bearing, Gas Supply, and Slosh Measuring Systems, Procedure for

MSFC-DWG-10M01671, Cleanliness Levels, Cleaning, Protection, and Inspection Procedures for Parts, Field Parts, Assemblies, Subsystems and Systems for Pneumatic Use in Support Equipment, Specification for

MSFC-PROC-245, Carbon Tetrachloride Scrubber Method for Analysis of Condensable Hydrocarbon Contamination in Compressed Gases, Procedure for

MSFC-DWG-A10419906, Cleanliness of Components for Use in Gyro Air Supply System, Specification for

ASTM D 1025-52, Nonvolatile Residue of Polymerization Grade Butadiene

ASTM D 1353-65, Nonvolatile Matter in Lacquer Solvents and Diluents

ASTM D 2109-64, Nonvolatile Matter in Halogenated Organic Solvents and Their Admixtures

FST-2, Quality Specifications and Methods of Analysis for Freon Precision Cleaning Agent.

4.2.3 Removal of Contaminants from Liquids

Contaminants may be removed from liquids by physical, thermal, or chemical processes. The complexity of the process may be fairly simple (for some particulates) or highly involved (for liquids having similar vapor pressures).

Contaminants may be removed from liquids in many ways, any one of which may be the most feasible for a given situation. Some of the factors which will influence the selection of a particular method are:

a. The volume of liquid to be processed

b. The type of contaminants to be removed

c. The boiling point and vapor pressure of the liquid (and of the contaminant also, if it is a liquid)

d. The specific gravity of the contaminant

e. The degree of purity required

f. The time required for purification or output rate of the process

g. Economic considerations of space, initial purchase, operation, personnel, and maintenance.

The primary methods of removing contaminants from liquids are summarized in Table 4-9.

TABLE 4-9

Methods for Removing Contaminants from Liquids

Removal Method	Principle	Type of Contaminant Removed
Distillation	Evaporation and condensation	Liquids Nonvolatile residue Particulates Microbial organisms
Sedimentation and drain off	Gravity settling	Particulates
Filtration	Straining Adsorption Absorption Magnetic attraction	Particulates Microbial organisms
Centrifugation	Gravity	Particulates Microbial organisms
Deionization	Ion exchange	Dissolved minerals in water

Some of the characteristics, limitations, and applications of these methods are described as follows.

a. Distillation -- Apparatus for this method can vary from a simple laboratory setup to large, sophisticated distillation systems. Along with filtration, this is probably the most universally used method for purifying liquids because it will remove most of the contaminants normally found in liquids in a relatively economical manner. Distillation plays an important role in the reclamation of manufacturing grade solvents and in the repurification of technical or precision grade solvents. A typical distillation process and system are shown in Figures 4-6 and 4-7.

b. Sedimentation -- This is a time-consuming but effective method for removing particulate matter from liquids. It is generally applied to removing gross particulates and is not recommended when extremely high purity is required. The purity attainable is a function of:

(1) the time allowed for settling

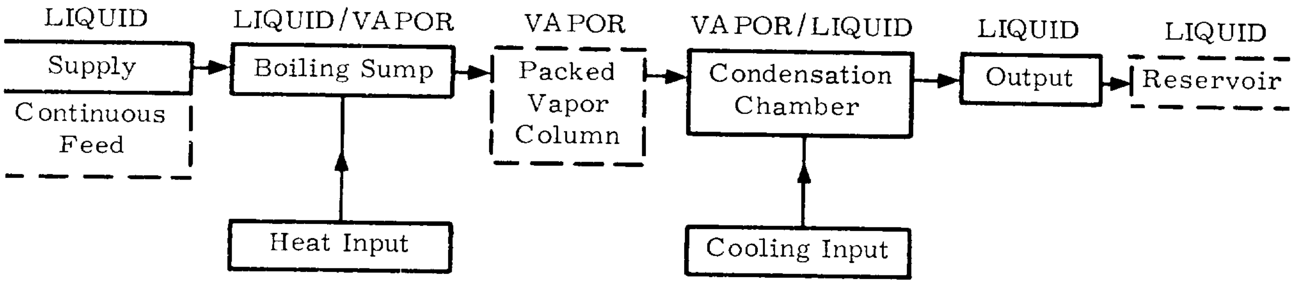
(2) the specific gravity of the contaminant as compared to that of the liquid

(3) the degree to which agitation of the liquid can be controlled and minimized.

The purified liquid is usually drawn off at a point in the upper portion of the container and the sediment is discarded. An exception to this procedure is the removal of heavy sludge from industrial washers by sludge conveyors.

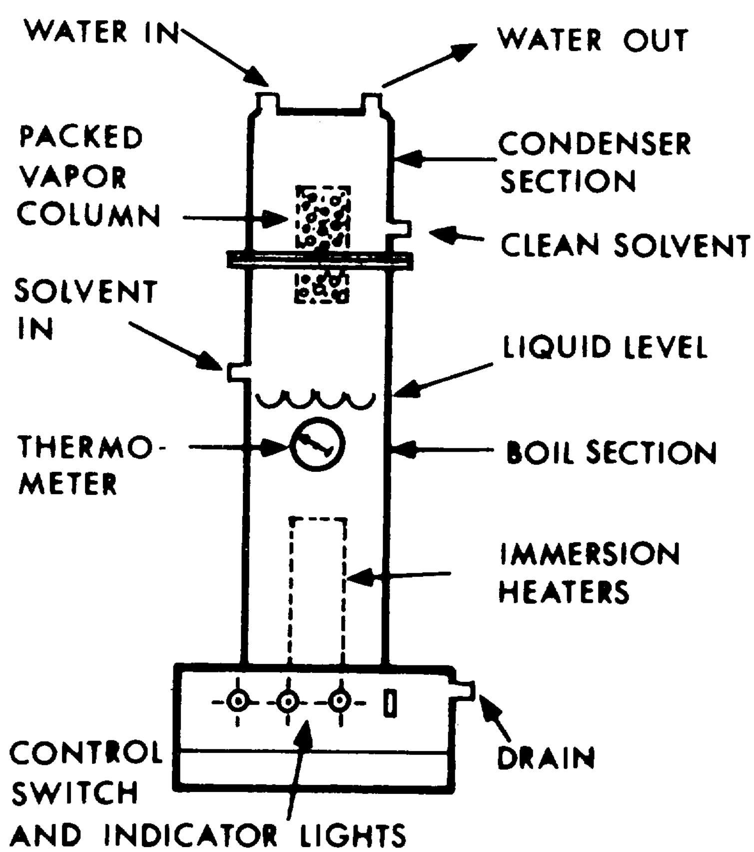
c. Filtration -- All filters perform the basic function of collecting and retaining contaminants. The type of filter selected for a particular application should be determined by the type and size of contaminant encountered, flow rates, and purity level desired, and the anticipated filter cleaning or replacement frequency. Some filters such as wire screens, perforated metal, and the larger pore size porous metal can be cleaned; most other types must be discarded and replaced. Filters may be used in-line to filter the entire volume of liquid in either batch or recirculating systems, or they may continuously filter only a portion of the liquid, as in the case of some ultrasonic cleaners. Membrane filters in flat or extended area configurations are used almost exclusively for filtering ultrapure liquids. Additional information on the types of filters available is contained in Paragraph 4.2.1.

d. Centrifugation -- This principle is similar to that of sedimentation. The primary difference is the time required for particulate removal. High-speed centrifuges greatly accelerate removal time for even those substances with very little difference in specific gravity. Centrifugation is used widely in removing microbial organisms from a liquid.



Solid lines indicate basic components and dashed lines optional components. Notations above the blocks indicate the physical state of the contents at that point in the process.

Figure 4-6. Diagram of a typical distillation process



Courtesy of Baron-Blakeslee, Inc.

Figure 4-7. Typical distillation system

e. <u>Deionization</u> -- Dissolved mineral ions can be removed from water by deionization. Figure 4-8 shows a typical continuous recirculation system for deionized water. Resin bed "C" on the left removes the cationic impurities by exchanging the cationic impurities for hydrogen ions. Resin bed "A" on the right removes the anionic impurities in a similar exchange action. Mixed bed exchangers can accomplish the same result as the two-bed system and may be used downstream in addition to the two-bed system. Virtually, all dissolved contaminants can be removed from water in this manner. Further information on deionized water is found in Paragraph 3.4.1.

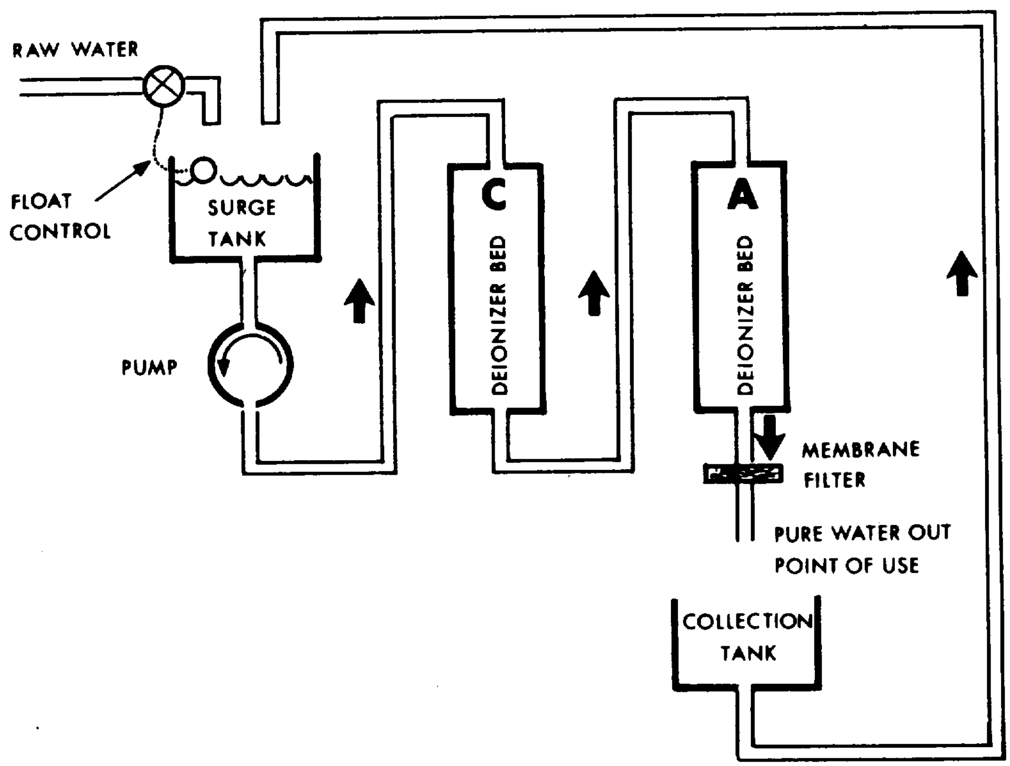


Figure 4-8. Typical deionized water system

Dilution and replacement contribute to the control of contaminants, although they are not methods for separating and removing contaminants from liquids. Dilution in this case is partial replacement of a contaminated liquid with a clean liquid of the same type. This may be done on a continuous or batch basis to maintain a minimum cleanliness level. Total replacement is commonly used when other methods of purification are not practical.

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SECTION 5

CONTROL OF AIRBORNE CONTAMINATION

The natural atmospheric air encountered near the surface of the earth is a composite of gaseous elements and compounds, water vapor, and some particulate matter from natural sources. Table 5-1 lists the components that may be present in natural air with the approximate concentrations for each. The concentration of water vapor or humidity will vary from one region to another and within any period of time. The type and quantity of particulate matter will vary widely as affected by the natural conditions in a region. Other gaseous components may also be present in natural air under certain conditions caused by natural occurrences.

The composition of natural air is substantially changed by human activities on and near the surface of the earth. The industrial, commercial, and domestic activities of man produce an ever increasing volume of gaseous components and particulate matter emitted into the atmosphere to pollute the air. The wide variety of contaminants produced by human activities results in changes to the concentrations of gaseous constituents of natural air, adds a variety of new gaseous constituents, and adds a wide variety of types and quantities of particulate matter.

If an airborne contaminant is defined as any airborne substance that adversely affects the contaminee, all components of the ambient air must be considered as possible contaminants. In some instances, only particulate matter of substantial size may be a contaminant; whereas, in other instances virtually all components of the air may be contaminants and must be excluded in some manner.

The production of precise, highly reliable devices requires exacting control of the environments for manufacturing, assembly, storage, and operation of these devices. The environmental conditions relating to the ambient air that require positive control within certain predetermined limits include temperature, humidity, and airborne contamination. Facilities for the control of temperature and humidity that are currently available normally provide the controls adequate to the needs of the product.

The development of facilities and equipment to control airborne contamination within a controlled environment area requires consideration of the major sources of contaminants. These include the air supply and activities within the controlled area.

a. Air Supply -- The ambient air prior to its introduction into the controlled area must have all contaminants removed or reduced to some predetermined level of cleanness consistent with the requirements of the operation being performed. Methods and facilities that may be used to cleanse the air of gaseous contaminants and the filtration of particulate matter to desired levels are covered in other parts of this handbook.

TABLE 5-1

Composition of Natural Air

Constituent	Approximate Concentration	
Nitrogen (N_2)	78.03	volume percent
Oxygen (O_2)	20.99	volume percent
Carbon dioxide (CO_2)	0.03	volume percent
Argon (A)	0.94	volume percent
Neon (Ne)	0.00123	volume percent
Helium (He)	0.0004	volume percent
Krypton (Kr)	0.00005	volume percent
Xenon (Xe)	0.000006	volume percent
Hydrogen (H_2)	0.01	volume percent
Methane (CH_4)	0.0002	volume percent
Nitrous oxide (N_2O)	0.00005	volume percent
Water vapor (H_2O)	Variable	
Particulate matter	*Variable type and quantity	
Ozone (O_3)	**Variable	
Formaldehyde (HCHO)	***Uncertain	

*The types and concentrations of these substances may vary substantially from one region to another and within any period of time from natural conditions.

**From ultraviolet radiation and probably thunderstorms, concentrations will vary from 0 to 0.07 ppm.

***From biological sources or oxidation of CH_4; possible concentrations not determined.

b. Activities Within the Controlled Area -- A wide variety of contaminants may be generated and emitted into the otherwise clean airstream within the controlled area from numerous sources which include personnel, tools and equipment used, and the various operations performed. Some of the major sources and types of operations with types of contaminants generated are shown in Table 5-2.

TABLE 5-2

Major Sources and Types of Contaminants Generated in Controlled Areas

Personnel	Fabrication	Assembly	Test	Handling
Bacteria Scale Hair Cosmetics Smoke Lint Fibers Body vapors Skin oils	Smoke fumes Dust Chips and burrs Chemical vapors	Wear particles Material shedding Corrosion products Sublimated materials Flux vapors Outgassing products	Test agent by products Radioactive materials Wear products	All listed in preceding columns

Factors to be considered in the control of contaminants generated within a controlled area include:

(1) adequate area to accommodate the operations and ease of access for maintenance of the facility

(2) architectural design for ease of cleaning and good clean down capability

(3) location of operations to minimize migration of contaminants from one operation to another

(4) selection and acquisition of tooling, equipment, and testing devices to minimize contaminant generation

(5) selection and training of personnel to be minimum contributors of contamination

(6) selection of personnel garments which are low shedding with minimum working restraint

(7) fabrication and assembly processes and procedures to minimize generation of contamination

(8) rigid enforcement of precise operating procedures and practices to minimize generation of contaminants

(9) employment of a monitoring system that accurately determines acceptable levels of contamination within the controlled area during all operations.

Other significant items to be considered in controlling airborne contaminants within a controlled area and maintaining acceptable levels of cleanliness are:

a. The Agglomeration Characteristics of Particulate Matter -- Particulate matter while suspended in the airstream has a significant tendency to agglomerate wherein small particles of matter will build larger and larger to a point where they may well exceed the allowable tolerance limits. Organic matter is more susceptible to this occurrence. The agglomeration of dissimilar materials involves the affinity of some types of matter for droplets of moisture or oils.

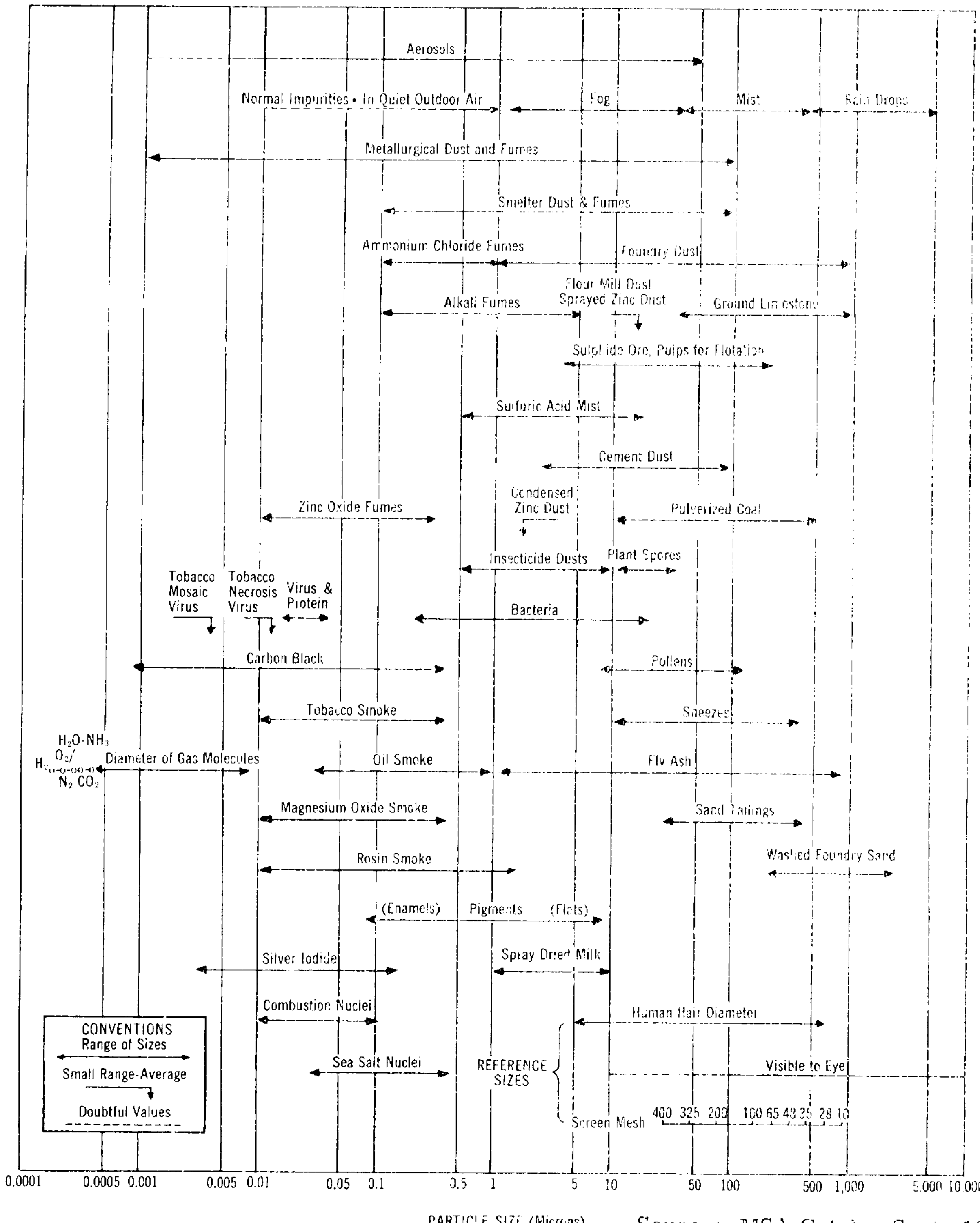
b. The Sizes of Airborne Particulates -- The size of particulates as potential contaminants is significant as related to the affect on the contaminee and the methods required for filtration. Figure 5-1 shows the relative sizes of particulates commonly found in ambient air.

5.1 Atmospheric Air Contamination

Normal atmospheric air is composed of both natural air and foreign constituents. The volume of various classes of contaminants that make up the foreign constituents of atmospheric air determines the pollution level of air as it affects physiological reaction, toxicity, visibility, damage to vegetation, and soiling and damage to materials exposed to air. Pollution of air is usually the result of some activity which emits undesirable substances into air in either one or a combination of the physical states classified as "gaseous" and "nongaseous." Sources of the contaminants polluting the air are the activities taking place on the surface of the earth and are divided into two broad classes: natural and man-made.

Natural sources result from physical and biological processes in the earth's environment and include dusts or minerals ventilated from the soil, ash from volcanic eruptions, salt-water crystals blown from the surfaces of large bodies of water, and airborne bacteria and pollen spores from a variety of plant life. The atmosphere also absorbs quantities of solar and cosmic radiation from outer space.

Man-made sources result from the varied activities of modern civilization. These involve industrial operations, vehicular, marine and aerial forms of transportation, distribution of raw materials and manufactured products, centralization of power and heat sources, together with all services necessary to the construction and maintenance of a community. The level of pollution and the classes and concentrations of various contaminants will vary widely with different geographical areas or zones. These are influenced by the air-pollution potential from the sources in the air-pollution zone, and the saturation potential of the air space over the zone.



Source: MSA Catalog Sect. 10
Mine Safety Appliances Co.
Pittsburgh, Penn.

$$1 \text{ micron} = \frac{1}{1000 \text{ mm}} \text{ or } \frac{1}{25{,}400 \text{ in.}}$$

Figure 5-1. Relative sizes of airborne particulates

The saturation potential is the capacity of the air space which envelopes a pollution zone to absorb, build up, and retain the air contaminants to levels which adversely affect the area as a whole. The saturation potential is normally realized when the rate of evacuation in the air space is less than the rate at which pollutants enter the air space. The rate of evacuation in the air space is controlled principally by the variable meteorological conditions in the area; the mechanisms of evacuation are:

a. Dilution or diffusion with uncontaminated air, facilitated by agitation or turbulence of the airflow

b. Dispersion of the entire polluted air parcel vertically or horizontally, facilitated by movement of air masses

c. Precipitation by entrainment or nucleation of particles by water droplets in rain or fog

d. Normal gravity fallout.

The air-pollution potential of a zone is the capacity for the various sources in the areas to emit contaminants in significant volume called primary contaminants, together with the capacity for these primary contaminants to interact or be modified by natural forces in the atmosphere resulting in secondary contaminants. The diversity and complexity of the sources capable of emitting such a wide variety of primary contaminants coupled with the secondary action result in virtually all chemical substances and derivatives or oxidation products known to chemical technology, and perhaps include some that are unknown. To determine what contaminants are in the air requires a sampling of the air to identify and measure the contaminants and an investigation of the sources to identify and measure the volume of the primary contaminants being emitted into the air.

The significance of the pollution of atmospheric air with its inherent variety of contaminants is principally the effect such contaminants have on a specific contaminee, including the effects on the environments in which they are found.

5.2 Classification and Sources of Airborne Contaminants

The activities of man are the major potential source of airborne contaminants; and the greatest potential for controlling this pollution is at the source. Classification of the various types of contaminants as related to the principal sources is essential in establishing measures for controlling air pollution.

5.2.1 Contaminant Classification

Airborne contaminants are classified by physical state as gaseous and nongaseous. Those in the gaseous state are further classified as "organic gases" and "inorganic gases." Those in the nongaseous state are known as "aerosols" and include all solid and liquid particulate matter.

Organic gases are compounds composed of atoms of carbon to which may be attached atoms of one or more of the elements such as hydrogen, oxygen, sulfur, nitrogen, or a halogen.

Inorganic gases result primarily from combustion reactions with oxides of sulfur and carbon monoxide formed by the oxidation of sulfur and carbon in combustible materials, and oxides of nitrogen being formed by the fixation of nitrogens at the high temperatures encountered in the combustion process.

Aerosols in liquid and solid form are emitted from a variety of sources both man-made and natural which include smoke, ash, soot, oil mists, and dusts and pollens in the natural state.

Table 5-3 is a classification of airborne contaminants by major class and subclass with typical members of each subclass.

TABLE 5-3

Classification of Airborne Contaminants

Major Classes	Subclasses	Typical Members of Subclasses
Organic gases	Hydrocarbons	Hexane, xylene, ethylene, pentane, butane, butadiene, methane
	Aldehydes and ketones	Formaldehyde, acetone
	Other organics	Chlorinated hydrocarbons, alcohols
Inorganic gases	Oxides of nitrogen	Nitrogen dioxide, nitric oxide
	Oxides of sulfur	Sulfur dioxide, sulfur trioxide
	Carbon monoxide	Carbon monoxide
	Other inorganics	Hydrogen sulfide, ammonia, chlorine
Aerosols	Solid particulate matter	Dusts, smoke, fumes, ash, soot
	Liquid particulate matter	Oil mists, entrained liquid droplets

5.2.2 Contaminant Sources

The diverse activities of man and nature which produce the contaminants discharged into the atmosphere are classified into eight general categories. The commercial or industrial activities such as production and manufacturing operations are the most significant sources of air pollution. However, the individual activities of man contribute heavily to the atmospheric pollutants, especially in densely populated areas.

a. Petroleum Industry -- This operation constitutes a significant potential for air-pollution emissions, including all classes of contaminants, from the production of crude oils to the marketing of finished products.

   Crude oil production encompasses those operations employed in obtaining the petroleum from the well, measuring, storing, and transferring the oil to the refinery. The contaminants consist chiefly of escaping natural gases and evaporated hydrocarbons (ethane and methane) with some carbon monoxide, oxides of sulfur and nitrogen, and aerosols emitted from internal combustion engines and other combustion equipment associated with the operations.

   Refinery operations and equipment include fluid catalytic cracking units, hydrocarbon storage, effluent waste disposal, flares, desulfurization and sulfur scavenging equipment. The contaminant emissions from these operations include all classes and subclasses with the major volume being hydrocarbons, oxides of sulfur and nitrogen, and carbon monoxide.

   Marketing and distribution of petroleum products comprise extensive facilities such as pipelines, terminals, tank trucks, and storage and loading equipment. Contaminant emissions are chiefly hydrocarbon vapors from storage tanks and transfer operations with some additional emissions from liquid spillage and from pumps and separators.

b. Metallurgical Industry -- This activity includes metal melting of both ferrous and nonferrous metals. The ferrous group includes gray iron foundries, steel foundries, and secondary steel mills. The nonferrous group includes foundries making castings of brass, bronze, aluminum, zinc, lead, and magnesium, as well as secondary smelters used in the recovery of these metals. Air-contaminating emissions from these operations consist principally of aerosols including smoke, dusts and metallic fumes, with some gaseous contaminants being emitted from combustible materials burned in the processes. The volume of gaseous contaminants in some instances is quite negligible and depends on the methods used in melting the metal, the type of metals, and contaminants or impurities in the metal.

c. Organic Solvent Usage -- Organic solvents are those organic liquids capable of being evaporated into the atmosphere during usage or storage. They are used to dissolve, dilute or disperse other substances without themselves chemically reacting with the other substances. The evaporation emissions of solvent vapors include all members of organic gas contaminants dependent upon the type of solvent, with the volume of vaporic emissions dependent on the volume of atmospheric exposure. Major sources may be identified by the types of equipment used which expose large volumes of solvents to vaporization. This equipment includes:

(1) solvent storage tanks

(2) solvent degreasers

(3) spray booths

(4) coating, baking, and drying ovens

(5) dry-cleaning equipment

(6) solvent mixing and dissolving tanks

(7) solvent crystalizing equipment.

d. Mineral Processing -- The major activities in this category include asphaltic concrete batching, concrete batching, glass container manufacture, ceramic glaze and enamel frit manufacture, mineral insulation manufacture, and many other mineral processing activities. The principal contaminants released by these activities are in the aerosol class, primarily dusts and fumes from such processes as crushing, grinding, milling, conveying, bagging, mixing, and blending. Some inorganic gas contaminants will be included in some activities from combustible materials burned in furnaces, heaters, and power equipment used in conjunction with the process.

e. Motor Vehicles -- This category involves primarily the operation of vehicles powered by gasoline or diesel engines. The exhaust from these vehicles is responsible for the largest volume of contaminants, principally carbon monoxide, hydrocarbons, and oxides of nitrogen with some aerosol emissions of smoke and carbon soot. The blowby or leakage of unburned gasoline into the crankcase contributes a substantial amount of hydrocarbon emissions with some carbon monoxide. The evaporative emissions from the fuel in the carburetor and fuel tank are principally hydrocarbon and some other organic gases. Additional particulate contaminants are emitted in the normal operation of vehicles from the cooling and braking systems to the scrubbing of tires on road surfaces.

f. Combustion Processes -- This includes those activities utilizing various fuels in a combustion reaction to produce heat and power for both domestic and commercial use. Such activity and equipment range from home space heaters and kitchen stoves to large steam electric power plants, and from the burning of combustible wastes and refuse in incinerators to open burning. The combustion of fuels in the various types of equipment to produce heat and power generates a variety of air contaminants in all classes. The composition of the fuel burned and the efficiency of the equipment used have a decisive influence on the types and quantities of air contaminants emitted.

However, the principal contaminants in most operations are hydrocarbons, aerosols, and oxides of nitrogen and sulfur. The principal contaminants from incinerators and open burning are the same as for fuel burning equipment plus considerable quantities of carbon monoxide.

g. Other Industry -- This includes all other industrial and commercial activities that are potential sources of air contaminants and are capable of emitting contaminants of significant magnitude. Some of these are manufacturers of paints, varnishes, synthetic resins, and asphalt, and the operation of spray booths, protective coating bake ovens, rendering plants, coffee processing, and feed and grain plants.

h. Natural Environment -- This category covers the natural sources of contaminants such as plants and animals. The principal class being aerosols such as pollens, spores, plant fibers, insect and animal parts, and bacteria and viruses.

The wide variety of equipment that may be used and the method of operation employed in a given activity or operation has a decisive influence on the volume and classes of contaminants emitted. Table 5-4 lists the eight general categories with some typical operations and shows the classes of contaminants that may be expected in significant volume from each. To further emphasize the volume of contaminants that may be emitted by certain operations, Table 5-5 lists a variety of combustible materials with the volume of significant contaminants emitted in the combustion process. The emission factors in this table are based on data collected by the Division of Air Resources, New York State Department of Health.

5.3 Control Techniques for Atmospheric Air Contaminants

The capacity to prevent air pollution in a specific area is limited to reducing the potential sources through one of the following methods:

a. Eliminating the source

b. Controlling source area pollution by zoning

c. Controlling or changing the sources.

The elimination of all sources of air pollution may not be practicable or possible. Specific instances of eliminating nonessential activities or substitution of equipment or processes may be applicable.

Zoning or placement of potential sources in specified areas to minimize the effects of air pollution can be quite effective. However, this method requires advance planning or movement of source activities which may not always be practicable.

TABLE 5-4

Sources of Contaminants

	Organic Gases			Inorganic Gases				Aerosols
	Hydrocarbons	Aldehydes and Ketones	Other	Oxides of Nitrogen	Oxides of Sulfur	Carbon Monoxide	Other	Liquid and Solids
Petroleum								
Refining	#	#	N	#	#	#	#	#
Marketing	#	N	N	#	N	N	N	N
Production	#	N	N	#	N	N	N	N
Metallurgical								
Nonferrous	N	N	N	N	#	N	#	#
Ferrous								
Grey iron	N	N	N	N	N	#	N	#
Electric steel	N	N	N	N	N	N	N	#
Open hearth	N	N	N	N	N	N	N	#
Organic solvent								
Surface coating	#	#	#	N	N	N	N	#
Dry cleaning	#	#	#	N	N	N	N	N
Degreasing	#	#	#	N	N	N	N	N
Mineral								
Asphalt batching	N	N	N	N	#	#	N	#
Concrete batching	N	N	N	N	N	N	N	#
Glass and ceramic	N	N	N	N	#	#	N	#
Insulation	N	N	N	N	N	#	N	#
Motor vehicle								
Exhaust	#	N	N	#	#	#	N	#
Blowby	#	N	N	N	N	#	N	N
Evaporation	#	N	N	N	N	N	N	N
Combustion								
Heaters and boilers	#	N	N	#	#	N	N	#
Incineration	#	N	N	#	#	#	N	#
Other industry	#	N	N	#	#	#	N	#
Natural environment	N	N	N	N	N	N	N	#

- Significant Volume
N - Negligible Volume

TABLE 5-5

Emission Factors for Contaminants from the Combustion of Fuels

Sources of Emissions	Solids	SO_2 (1)	NO_2 (2)	Hydrocarbons	Organic Acids	Aldehydes	Ammonia
From combustion of coal (lb/ton) (Note 3)							
Bituminous	100	75	20	20	30	2	2
Anthracite	15	25	20	3	5	1	2
From combustion of fuel oil (lb/1000 gal) (Note 4)							
Residual #5 and #6	10	210	120	5	15	1	1
Oil distillate #1 and #4	10	85	70	5	15	2	1
From combustion of gas (lb/1,000,000 ft^3) (Note 5)							
Natural gas	10	0.6	180	70	60	10	0.5
Propane	26	1.7	450	180	155	26	1.3
Bottled butane	34	2.0	590	240	205	34	1.7
50% Propane - 50% Butane	30	1.9	520	210	180	30	1.4
From combustion of wood (lb/ton) (Note 6)	10	--	1.3	20	0.4	1.8	--
From combustion of diesel fuel in internal combustion engines (lb/1000 gal) (Note 7)	110	45 (7)	220	320	30	16	2
From combustion of gasoline in internal combustion engines (lb/1000 gal) (Note 8)	14	5	90	455	4	10	2
From incineration of refuse in incinerators (lb/ton)							
Large or multi-stage units	10	1.9	2.1	1.4	0.6	1.1	0.3
Small or single-stage units	20	0.3	0.6	20.0	10.0	3.0	0.3
From uncontrolled combustion of refuse (lb/ton)							
Paper burning	4.7	1.2	0.5	145	1.5	2.1	0.1
Garden trim burning	--	--	0.6	415	--	5.7	4.4
Open dump burning of refuse	30.0	0.3	0.6	80	40.0	3.0	0.3

NOTES:

1 - Sulfur compounds as SO_2.

2 - Oxides of Nitrogen as NO_2.

3 - Average coals used in New York State (source of this information), have heating values of 27,200,000 BTU/ton for Bituminous, and 25,200,000 BTU/ton for Anthracite coal.
If any control equipment is in operation, the tabulated factors should be reduced. If no efficiency rating is specified, use the following efficiencies:
Gravity settling chamber - 50% Cyclone collector - 85% Electrostatic precipitator - 95%

4 - For comparative fuels use: Residual oil = 150,000 BTU/gal; Distillate oil = 140,000 BTU/gal.
Typical weights: #1 = 6.8 lb/gal; #2 = 7.15 lb/gal; #4 = 7.65 lb/gal; #5 = 7.9 lb/gal; #6 = 8.2 lb/gal.
For oxides of nitrogen emissions from tangentially fired units use 1/2 tubular value.

5 - For comparative fuel use: Natural gas - typical weight 0.045 lb/ft^3 at 60°F and 30-in. Hg - average heating value 1000 BTU/ft^3. Commercial propane - typical weight 0.117 lb/ft^3 at 60°F and 30-in. Hg - typical volume 36.28 ft^3 at 60°F and 30-in. Hg/gal at 60°F - average heating value 2522 BTU/ft^3 at 60°F and 30-in. Hg. Commercial butane - typical weight 0.154 lb/ft^3 at 60°F and 30-in. Hg - typical volume 31.46 ft^3 and 30-in. Hg/gal at 60°F - average heating value 3261 BTU/ft^3 at 60°F and 30-in. Hg.

6 - For average heat value of air dried wood (20% moisture) use 7000 BTU/lb. A standard cord of wood has a volume of 128 ft^3 and an air dry weight of 1-1/2 to 2 tons/cord.

7 - Typical weight of diesel fuel = 6.8 lb/gal. SO_2 for this item is sulfur dioxide.

8 - Typical weight of gasoline = 6.25 lb/gal. Hydrocarbons (455) are derived from: Exhaust - 305; crankcase - 115; and car tank and carburetor evaporation - 35.

Controlling or changing the source may be accomplished by any one or any combination of the following actions:

a. Institute operational and maintenance techniques to rigidly control the handling of fuels, materials, and equipment to minimize contamination emissions.

b. Incorporate design features in equipment to efficiently utilize all materials and fuels to prevent contamination emissions.

c. Replace or alter the composition of fuels or materials to reduce or eliminate those volatile or impure elements which cannot be utilized or collected by the equipment.

d. Install control or collection devices which will either eliminate the contaminant through combustion or chemical reaction or collect the contaminant by entrapment.

The current air-pollution control technology provides a wide variety of techniques and devices to virtually the whole range of industrial activities with a considerable economic choice in the selection of suitable control methods. Most of the air-pollution problems can be controlled through available techniques. Some problems still require further engineering development for an adequate solution.

5.3.1 Air-Pollution Control Devices

When the design and operational efficiency are inadequate to control the emissions of air contaminants, specially designed control equipment becomes necessary. Control equipment is divided into two classes:

a. Aerosols -- Those which collect aerosols, solid and liquid form particulates, by one or more of the following principles:

   (1) inertial entrapment by altering the direction and velocity of the effluent

   (2) increasing the size of the particles by agglomeration or liquid mist entrainment so as to subject the particles to inertial and gravitational forces within the operational range of the device

   (3) impingement of particles on impact surfaces, baffles, or filters

   (4) precipitation of contaminants in electric fields or by thermal convection.

b. Gases -- Those which collect or control gases by one or more of the following principles, and which are based on the physical and chemical properties of the individual gases:

(1) combustion of volatilized gases

(2) absorption into reactive solutions

(3) adsorption to an active surface area of a solid

(4) condensed through temperature and pressure changes

(5) reduced to carbon dioxide and water through high-temperature controlled combustion

(6) catalyzed to harmless substances

(7) converted by chemical reaction to by-products

(8) conserved and reused by means of vapor collection.

Table 5-6 lists the types of devices used in controlling aerosol contaminants with some examples of the contaminants controlled and the principle of operation.

Table 5-7 lists the types of devices used on controlling some of the gaseous contaminants with some examples of the contaminants controlled and the principle of operation.

Figures 5-2 and 5-3 contain simplified diagrams of some of the devices used to control emissions of air contaminants.

5.3.2 Detecting and Measuring Atmospheric Air Contaminants

Some contaminants may be visible in the atmospheric air in the form of smoke or smog. However, when the density of such contaminants is below 40 percent opacity (No. 2 Ringlemann chart) or the contaminants are of a transparent nature, their presence is not readily apparent.

Specially designed equipment and skills for testing and measurement are required to determine what contaminants are present and what the levels of concentration are in a specific area. Within a specific geographic area or community, some information in this regard may be obtained from the federal and local agencies employed in air pollution control. Information from these agencies would include sources of air pollutants, types of contaminants and rates of emission, and types and concentrations of contaminants at air-sampling stations in the area.

Identifying and measuring the concentration of contaminants in a specific location or point within a plant or facility may be accomplished by on-the-spot testing. Factors to be considered in on-the-spot testing should include:

a. Variations in concentrations due to varying meteorological conditions

b. Hours of operation of source-emitting activities

c. Potential sources in the immediate vicinity

d. Specific types of contaminants most undesirable.

TABLE 5-6

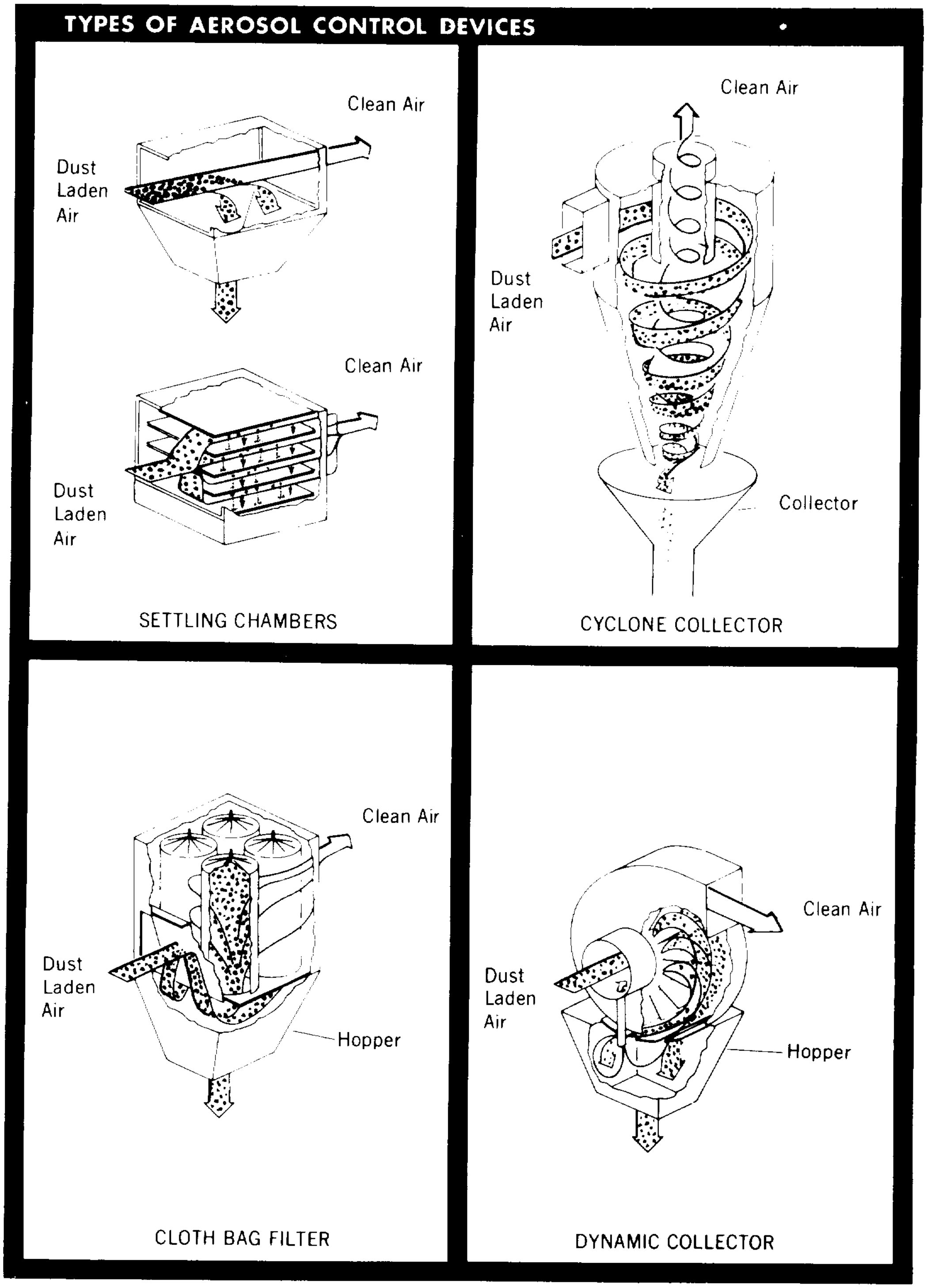
Air Pollution Control Devices for Aerosols

Type	Principle of Operation	Examples of Contaminants Controlled	Remarks
Settling chamber	Compartment permitting gravity settling of dusts	Wood, grain, mineral dust	Simple design, low efficiency, used as precleaner.
Centrifugal collectors (dry)	Single cyclone	Wood, grain, mineral dusts	Simple construction, low efficiency.
	Multiclone	Catalyst dust, fly ash	Relatively high efficiency.
	Impeller	Foundry dust	High efficiency, small space required.
Filters (fibrous, cloth or viscous)	Tubular (bag house)	Metallurgical fumes and fine dusts	High efficiency over wide range of particle size.
	Screen or frame	Ceramic dust, foundry dust	For small or intermediate size operations.
	Tubular bag with reverse jet cleaning	Carbon black, flour dust, grain dust	High filter ratios but bag wear increased.
Electrical precipitators	Single stage (high voltage)	Metallurgical fumes, catalyst dust	High efficiency under severe conditions, high cost.
	Two stage (low voltage)	Oil and acid mists	High efficiency, limited use.
Wet collectors (scrubbers)	Spray chamber	Rock dust, acid mist	Limited use, high nozzle pressure.
	Centrifugal	Rock and sand dusts, some mists	Many variations in design.
	Inertial	Grinding dust, foundry dust	Similar to cyclone with liquid tangential sprays.
	Venturi scrubber	Chemical fumes, acid mists	High efficiency, high first cost. High velocity carrier stream through venturi.

TABLE 5-7

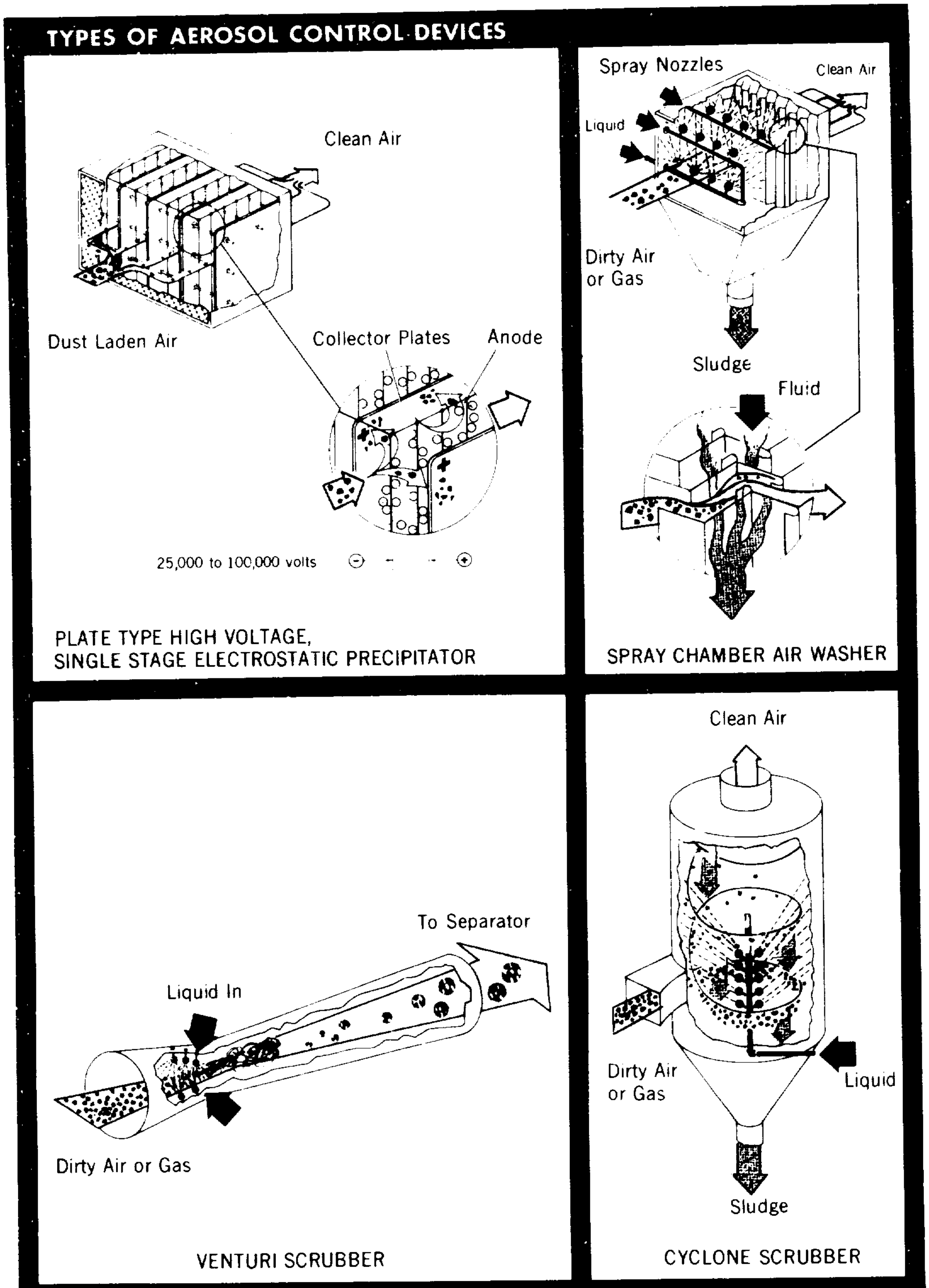
Air Pollution Control Devices for Gases

Type	Principle of Operation	Examples of Contaminants Controlled	Remarks
Absorbers	Packed towers	Malodors from rendering and chemical plants.	Solutions - oxidizing agents.
	Plate towers	Gases and vapors from refinery and chemical plants.	Solution - absorption oil (oil is stripped and recirculated).
	Spray towers and chambers	Hydrogen sulfide from thermal and catalytic cracking plants.	Solutions - ethanolamines, thylox, potassium phosphate, sodium phenolate. (Solutions are regenerated.)
		Sulfur dioxides from flue gases, chemical plants.	Solution - water solutions of sodium sulfite, ammonium sulfite and sulfate (replenished), dimethylamine (regenerated).
		Nitric acid from chemical plants.	Solution - alkaline solution.
Adsorption	Condensation on surface of a solid	Organic solvent vapors and malodors.	Adsorbents - activated charcoal, silica gel, activated alumina.
Incineration	Flares	Hydrocarbons from refineries and oil fields.	Venturi burners or steam injection for smokeless combustion.
	Fume burners	Hydrogen sulfide from refineries and chemical plants.	Sulfur dioxide is product of combustion.
		Gases and malodors from chemical plants, refineries, food processing.	High operating temperatures 900° to 1600°F.
	Catalytic combustion	Organic vapors, carbon monoxide, oil vapors, ammonia.	Catalysts - platinum, nickel operating temperatures 600° to 900°F.
Vapor recovery	Vaporsphere collection	Gasoline, crude oil, other volatiles from storage tanks.	Vapors may be compressed and liquefied, or burned as fuel or flared.
Floating roofs	Reduces tank breathing losses	Gasoline, crude oil, other volatiles from storage tanks.	Closure seals required for good efficiency.



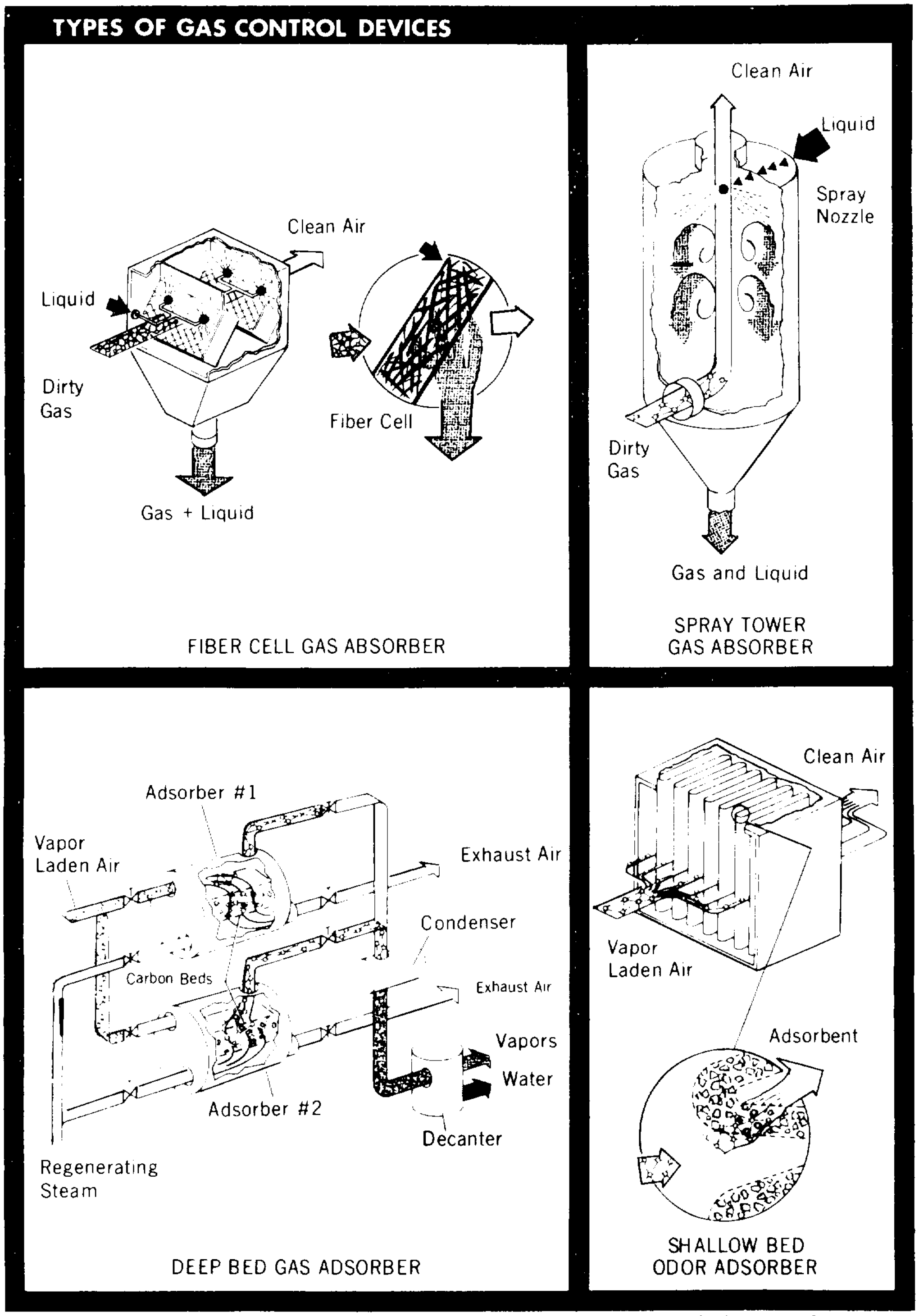
SOURCE: FAN ENGINEERING, Buffalo Forge Co., Sixth Edition 1961

Figure 5-2. Types of aerosol control devices



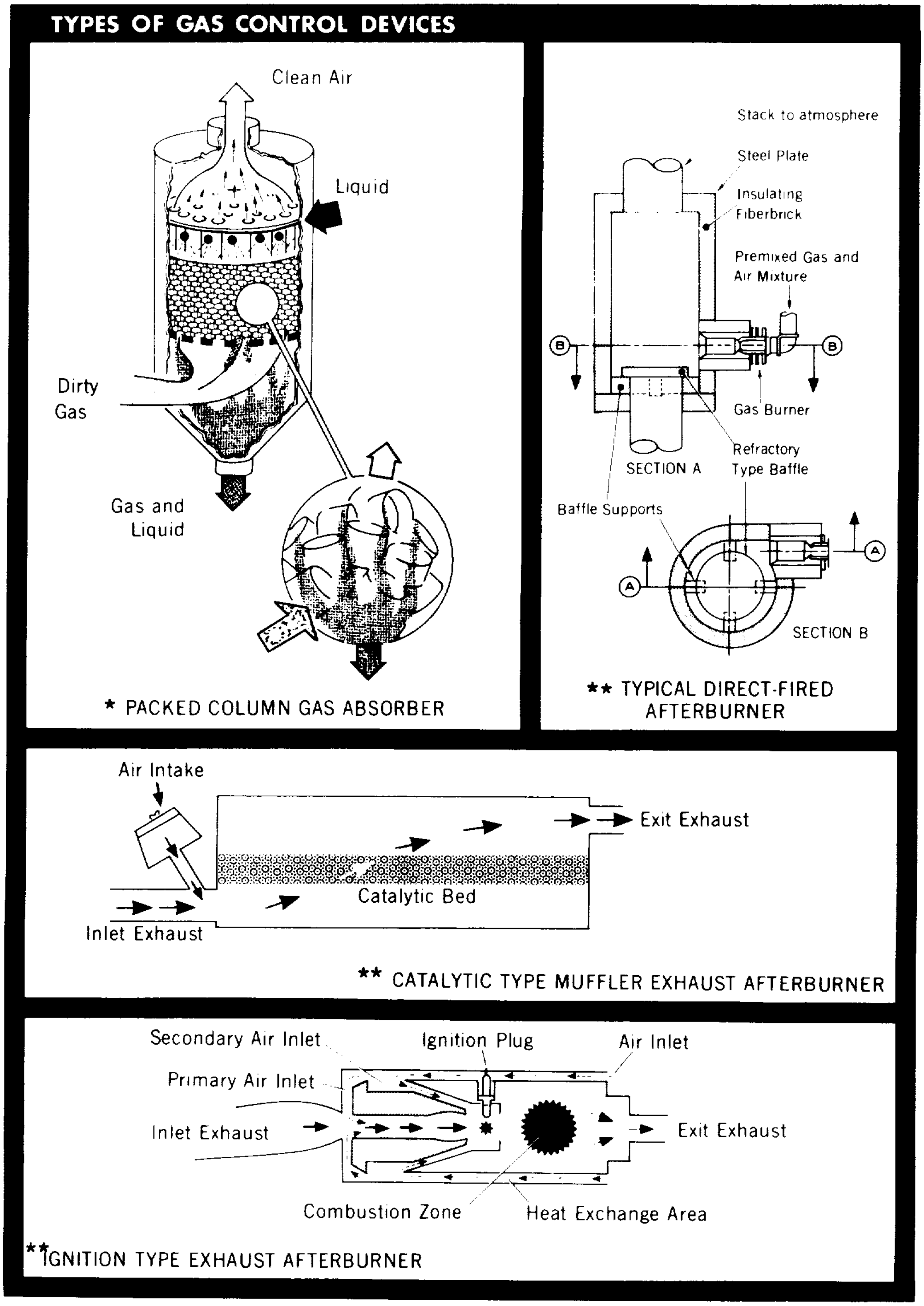
SOURCE: FAN ENGINEERING, Buffalo Forge Co., Sixth Edition 1961

Figure 5-2. (continued)



SOURCE: FAN ENGINEERING, Buffalo Forge Co., Sixth Edition 1961

Figure 5-3. Types of gas control devices



SOURCE: * FAN ENGINEERING, Buffalo Forge Co., Sixth Edition 1961
** AIR POLLUTION CONTROL FIELD OPERATIONS MANUAL
PHS Publication No. 937,1962

Figure 5-3. (continued)

Air sampling and test methods are divided into two groups:

a. Methods Applied to Particulates -- The effectiveness of testing for particulate matter may be affected by the solubility, or organic or inorganic nature of the material. However, the principal measurement parameters are size and volume or quantity. Particulate sampling devices employ the same principles used in the various types of source control equipment used by industry, but the sampling devices must be highly efficient for all particle sizes. Table 5-8 lists the types of sampling devices commonly used, with their principle of operation and some information on efficiency of collection. These devices are also used for sampling the effluent at the sources of emission.

b. Methods Applied to Gases -- The testing for gaseous contaminants consists primarily in separating the contaminant gas from other gaseous media (air). Sampling techniques for gases are adapted to either the sampling of a specific gaseous compound or determining gross contaminant concentrations. Specific methods are generally used for inorganic gases and, in most cases, involve an absorption method by bubbling through a reactive liquid agent or by exposing the contaminated air to impregnated papers and granules for colorimetric reaction. For sampling mixtures of contaminated gases, the freeze out, adsorption, and grab sample techniques may be used.

   Major types of test equipment which are capable of being used in the field with a reasonable degree of accuracy are listed in Table 5-9. This type of equipment is sufficiently portable for on-the-spot testing and may be used for testing at the sources. For greater accuracy in measurements and identification of a mixture of contaminating gases at the sources, more sophisticated sampling equipment may be used with laboratory analysis of the sample. Some gaseous contaminants commonly encountered due to their widespread use in, or by-products from, industrial activities are listed in Table 5-10 with reagents and equipment used for testing, concentration ranges, and threshold limits. The concentration ranges shown are the limits of the test equipment used. The threshold limit value (TLV) is a guideline between safe and probably dangerous concentrations having adverse effects on personnel, as recommended by the American Conference of Governmental Industrial Hygienists.

5.3.3 Air-Supply Conditioning

The purpose of conditioning the air supply for industrial buildings and facilities is to promote the health, comfort, efficiency, and safety of the personnel, and to maintain an environment favorable to the operations, processes, materials, and equipment. To provide these conditions requires the employment of methods to control temperature, humidity, distribution, ventilation, and contamination.

TABLE 5-8

Sampling Devices for Particulates

Type	Principle of Operation	Remarks
Sedimentation and settling Chambers Jars Petri dishes Trays Gum paper	Collects particulates which settle out of the atmosphere.	For rough quantitative analysis. Generally limited to estimating dust fall trends in an area.
Inertial or centrifugal midget cyclone	Whirling, spiraling motion of the airstream causes particles to separate from the airstream by centrifugal deflection.	Simple in design, temperature resistant with low pressure drop. Close to 100-percent effective in collecting particles over 10 microns in size.
Filtration Soluble filters Insoluble filters	Suction-type blower system which draws air through specially selected filter medium. Soluble filter may be dissolved to recover particles.	Useful in collecting almost unlimited quantities of particulates for measurement of mass quantity, soiling properties, chemical analysis, counting, sizing, and measuring radioactivity.
Impingement Wet Dry	Separates particles from the air by sudden changes in direction of the airstream impinging the particles on special surfaces.	Wet type used for collecting fine particles. Dry type limited to collecting large particles.
Cascade impactors	A series of impingement stages through which the velocities of the airstream systematically varies, sorting and collecting particles on collodion screens or microscopic slides.	Almost 100-percent efficient in sorting and collecting particles ranging in size from 0.7 to 50 microns.
Electrostatic collectors	Ionization of particles by means of a platinum electrode with particles being collected on a removable electrode of the opposite charge.	Highly efficient for particles ranging below 1 micron in size.
Thermal precipitators	Particles in a slow moving airstream between hot and cold surfaces settle on the cooler surface, collected on a coated grid for microscopic examination.	Limited to a narrow range in particle size dependent on the rate of the airstream movement.

TABLE 5-9
Sampling Devices for Gases

Type	Principle of Operation	Remarks
Test papers	Sensitized papers that change color when exposed to certain concentrations of some gases, fumes, or dusts.	Used to test for some contaminants such as ammonia, hydrogen sulfide, phosgene, etc.
Squeeze bulb and ampules	Squeeze bulb aspirator with glass tube ampules packed with treated granules. Reagent in the granule surfaces gives colorimetric reactions for specific contaminants.	Mine safety appliance (MSA) gas testers constructed for specific contaminants. Limited to concentrations of 1 ppm or greater.
Tutweiler apparatus	Analysis by gas/liquid titrations. Consists of a burette serving as a reaction chamber with a leveling bottle and a graduate mounted on top of burette with a two-way cock.	Measures concentrations above 150 ppm of ammonia, carbon dioxide, hydrogen sulfide, and sulfur dioxide.
Reich's test	Analysis by gas/liquid titrations. Metered amount of contaminated air bubbled through a solution of water, iodine, and starch in a graduated cylinder producing color change.	Volumetric determination of sulfur dioxide only.
Impingers and gas absorption cells	Hand-operated pump aspirator impinges contaminated airstream on specially prepared surfaces or absorption cells for colorimetric reaction.	Constructed for specific contaminates such as aldehydes and chlorine.
Halide leak detector	LPG fuel tank fitted with microburner with copper ring reaction plate above the flame tip. Tubular sampling line feeds the contaminated air to burner by natural draft. Flame color identifies contaminant and estimate of concentration.	Detects and determines the concentrations of halogenated hydrocarbon vapors such as carbon tetrachloride, trichloroethylene, and perchloroethylene.
Volume change measurement	Gas absorbed in a base substance. Volumetric measurement before absorption and of residual gases after absorption.	Carbon dioxide absorption in caustic-fyrite CO_2 analyzer. Oxygen absorption in pyrogallic acid-fyrite oxygen analyzer.
Explosimeters or combustion meters	Air sample aspirated through a reaction chamber with squeeze bulb and tubular sampling line. Meter and self-contained battery provides direct reading.	Used to test for combustible gases such as natural gas, carbon monoxide, and hydrocarbon vapors.

TABLE 5-10

Common Gaseous Contaminants

Contaminant	Test Equipment	Treatment or Reaction	Test Range	Threshold Limit Value	Physiological Response
Aldehydes (HCHO) (CHCHO)	Absorption in sodium bisulfite in MSA midget impinger	Iodometric titration	0-1000 ppm	5.0 ppm 0.5 ppm	Pungent, choking odor, irritating to eyes and throat.
Ammonia (NH_3)	Red litmus Stop watch	Color to blue	10-100 ppm	100 ppm	Pungent irritating odor, eye irritation.
Arsine (AsH_3)	MSA arsine detector	Treated filter papers change color	0-10 ppm	0.05 ppm	Slight garlic-like odor.
Carbon dioxide (CO_2)	Fyrite CO_2 analyzer	Absorption in caustic and measure volume change	0-20%	5000 ppm	No odor, respiration rate increases.
Carbon monoxide (CO)	MSA CO detector	Treated granules change color	0-1000 ppm	1000 ppm	Slight garlic-like odor, dizziness, headache.
Chlorine (CL_2)	O-tolidine in MSA midget impinger	Color intensity compared to standards	0-70 ppm	1 ppm	Pungent, choking odor, irritating to eyes, nose, and throat.
Hydrogen cyanide (HCN)	MSA hydrocyanic acid gas detector	Treated granules change color	0-50 ppm	10 ppm	Penetrating almond odor, irritation and constriction of throat.
Hydrogen fluoride (HF)	MSA hydrocyanic fluoride-in-air detector	Treated filter papers change color	0.5-5 ppm	3 ppm	Pungent, irritating odor, throat irritation.
Hydrogen sulfide (H_2S)	MSA H_2S detector	Treated granules change color	0-50 ppm	20 ppm	Rotten egg odor, headache, dizziness.
Nitrogen dioxide (NO_2)	Saltzman reagent	Color change measured	0-10 ppm	5 ppm	Pungent, sweetish odor.
Oxygen (O_2) (deficiency)	Fyrite oxygen analyzer	Absorption measure volume change	0-21%	18-21%	Below tolerance range causes anoxia with progressive impairment of behavior.
Phosgene ($COCL_2$)	Treated filter papers	Color change compared to standards	1-100 ppm	1 ppm	Musty hay odor.
Phosphine (PH_3)	Treated granules	Color stain length measured	1-10 ppm	0.05 ppm	Foul decayed fish odor.
Sulfur dioxide (SO_2)	MSA SO_2 detector	Measure length of bleaching action	1-150 ppm	5 ppm	Burning sulfur odor, throat and eye irritation.
	Reich's test	Gas titration	0.20%		
	Tutweiler apparatus	Gas titration	50 grains/ft^3		

Human comfort is influenced principally by temperature, humidity, and velocity of air in the work area. Control of these factors within effective ranges for normal requirements are within the capabilities of a well-designed and engineered air-conditioning system. A system of this type should provide for the exhausting of odorous and toxic fumes and for the introduction of fresh air into the air-supply system. Some control of contaminants may be included, depending on the volume of contaminants in the unfiltered air and those generated within the plant and recirculated throughout the plant area. Air washers, filters, or electric precipitators or combinations of these units are normally adequate to reduce the airborne contaminants to tolerance levels acceptable to the health and safety of personnel.

Special consideration must be given when environmental conditions required for certain operations, processes, material, or equipment are more critical than normally provided. The more critical environmental controls can be provided by establishing zones or areas in which special control methods are employed. Control facilities for the environmentally controlled areas may be auxiliary equipment to the regular system or a completely separate system. Facilities may be required to control:

a. Temperature, for close-tolerance machining, cold room storage, etc.

b. Humidity, for minimizing rust and corrosion, eliminating static electricity, etc.

c. Contaminants, such as aerosols, gases, and vapors.

The control or reduction of airborne contaminants in a specially controlled area involves any one or combination of the following contaminant types:

a. Particles of solid or liquid substances (aerosols)

b. Vapors of substances which are solid or liquid in their concentrated form and gases not normally found in natural atmospheric air

c. Water vapor and gases other than oxygen, nitrogen, and argon in amounts exceeding that normal for natural air are also considered a contaminant in the area of control.

Particulate matter is removed by one or a series of mechanical filters or devices such as:

a. Filters (fibrous, cloth or viscous)

b. Impingement filters (wet or dry)

c. Electrostatic precipitators

d. Scrubbers

e. Adsorption (within limits of adsorbent).

Gases and vapors are removed by absorption, adsorption, and chemical reaction (catalysis).

A typical air-purification system may include the following types of equipment:

a. Ventilation-type dust filters for reducing high and medium density dust loadings of the air

b. Intermediate efficiency-type filters for high velocity particulate filtration of low density dust loading

c. Activated charcoal filters remove or reduce concentrations of vapors, fumes, and odors.

The series of filters is followed by the air-tempering equipment for control of temperature and humidity. The dust and high-velocity filters are placed ahead of the charcoal filter to protect it from being overloaded with particulate matter, thereby increasing the service life of the charcoal. This type of system permits total recirculation of air, thereby reducing the operational requirements of the air-tempering equipment and providing adequately clean air for normal operations. The service life of high-efficiency filters used for clean room and clean bench operations is also extended by precleaning the air supply for these facilities.

The selection of filters for an air-supply purification system involves consideration of a number of factors, in order to provide adequately clean air by the most efficient and economic method. Criteria for filter selection are covered in Paragraph 5.4. The basic considerations are the identification and concentration range of the types of contaminants in the air supply and the cleanliness level required.

The selection of a filter media for the removal of gaseous contaminants is dependent on the types and concentrations of vapors and odors that must be removed from the air supply. Most industrial adsorbents are capable of adsorbing both organic and inorganic gases. Certain preferential characteristics and other physical properties make each one more or less specific for a particular application. Activated alumina, silica gel, and molecular sieves are preferential to water and may best be employed in reducing the humidity when required. Activated carbon (charcoal) is preferential to nonpolar organic compounds, but its preferential adsorption properties can be partially regulated by the type of surface oxide induced on the carbon. The following factors are the most important in the adsorption process that must be considered in the selection of adsorbents:

a. Particle size of adsorbent (may depend on maximum allowable pressure drop)

b. Depth of adsorbent bed

c. Air velocity

d. Temperature of airstream and adsorbent

e. Concentration of contaminants to be removed

f. Concentration of gases not to be removed, including moisture

g. Pressure of the system

h. Removal efficiency required

i. Possible decomposition or polymerization of contaminants on the adsorbent bed

j. Regeneration capabilities.

Activated charcoal is the most universally used adsorbent for air purification. It has a greater surface area for a given volume than any other product currently known. One cubic foot of activated charcoal contains approximately 200 million square feet of adsorptive surface. This tremendous surface area is but one of the factors contributing to the high adsorptive capacity for a wide range of gases normally encountered in air. Other factors include the type of raw material used and the activation process employed to control pore structure and size to some degree. The capacity of activated charcoal for any given gas is dependent on:

a. Type of activated charcoal used

b. Gas being adsorbed

c. Other gases present

d. Operating conditions: temperature, pressure, humidity, etc.

Some of the gases and vapors commonly encountered as contaminants in the air supply are listed below. The ones listed as high capacity are those for which activated charcoal has a high adsorptive capacity and are effectively and economically removed by standard commercially available filters. For those listed as low capacity, activated charcoal has a relatively low adsorptive capacity. The initial efficiency for effective removal of both groups of gases is high; therefore, the low capacity group is effectively removed when the concentrations are limited.

High Capacity	Low Capacity
Acetic acid	Ammonia
Acetone	Arsine
Asphalt fumes	Carbon dioxide
Carbon disulfide	Carbon monoxide
Chlorinated hydrocarbons	Formaldehyde
Cyanide	Formic acid
Engine exhausts	Nitric oxide
Hydrochloric acid	Stibine
Hydrogen sulfide	Sulfur dioxide
Methyl ethyl ketone	
Nitric acid	
Oil vapor	
Phosgene	
Phosphine	
Smog	
Tobacco smoke vapor	

Special techniques are employed to increase the capacity and effectiveness of charcoal for removing specific gases or vapors. Such techniques include the impregnation of the activated charcoal with additives and the employment of equipment for in-place regeneration of the charcoal.

5.4 Air Filters for Contamination Control Facilities

Air-supply systems normally utilize a filter media of porous fiber material. The fibers may be viscous coated or a dry type. The deposition or entrapment of particulate matter is by centrifugal, electrostatic, and diffusional forces employed in various degrees and combinations. Sieving or straining action is not a major action in this type filter except for large particles on and near the surface of the filter media. The air traversing the narrow winding passage within the porous filter bed is dispersed into many small streams that bring the entrained particulates in contact with filter fibers to which they adhere.

Filters differ in the degree to which they impede the flow of air. It may be assumed, as a rough guide, that for equal airflow rates the most effective filters for small particles will be associated with the highest airflow resistances. Filter resistance naturally increases as the filter ages (in use), because the accumulating particulates trapped by the filter progressively impede the flow of air. Eventually, airflow resistance increases up to the maximum capacity of the blower and after this, the total airflow decreases below the minimum required for the facility. When this occurs, the filter must be replaced, or cleansed if possible. The filter resistance is a direct measure of the power required to draw air through it. The airflow resistance of a filter element is a measure of the pressure drop or pressure difference between the input and output sides of the filter. The pressure drop is usually expressed in terms of inches of water as water gage (WG).

Since filters must be replaced or renewed when their resistance exceeds the capabilities of the air-moving system, service life of identical filters will vary according to the quantity and nature of the collected particulates, as well as the volume-static pressure characteristics of the air blower. If the filter loading doubles, service life will diminish by one-half, all other factors remaining the same. Large particles generally cause less filter resistance increase than an equal weight of smaller particles deposited on the filter. This is attributed to closer packing of small particles with a decrease in the size of the air passages. Other factors, such as particle shape, will also affect particle packing characteristics and subsequent resistance increase.

The thickness and porosity of the dust deposit that builds up on the surface are largely responsible for the resistance increase characteristics of paper and fabric filters. On the other hand, deep bed filters, composed of loosely packed fibers, have large storage capacity between the fibers and, therefore, filter resistance increase is modified by the fiber diameter and fiber arrangement. Fine diameter flexible fibers compress when the filter resistance exceeds the mechanical strength of the fibers, whereas beds of large-diameter, stiff fibers remain rigid even when plugged with dirt. When the buildup of dirt is excessive, there is a tendency for dirt to blow through a rigid structure.

The efficiency rating of air filters is a measure of particulate matter in the air collected by the filter media. This measure is expressed as a percentage factor based on the method employed in testing the efficiency. The three standard tests commonly used are:

a. Weight Test (Synthetic Dust) -- This test compares the weight of a test dust which passes through the test filter with the weight of the dust introduced into the airstream just ahead of the filter. This test is insensitive to fine particles and is not intended for testing high-efficiency-type (HEPA) filters.

b. Discoloration Test (National Bureau of Standards) -- This test is known as dust stop, photometric or blackness test of atmospheric dust. This test compares the degree of discoloration produced on two filter papers, one through which cleaned air is drawn and the other, uncleaned air. This test is insensitive to fine particles and is not intended for testing high-efficiency-type (HEPA) filters.

c. DOP Test -- A diotylphthalate (DOP) smoke is introduced on the upstream side of the filter and the downstream side is measured with an aerosol photometer to determine the total amount of smoke which passes the filter media. The DOP smoke consists of a homogeneous mixture of DOP vapor and clean air in a volume ratio of 1:4. The concentration is adjusted to approximately 40 grains per thousand cubic feet and the particle size to 0.3 micron. A HEPA filter should not permit more than 0.03 percent of the 0.3-micron size smoke to penetrate through the filter media for a 99.97-percent efficiency rating.

The differing factors in the test methods do not permit direct comparison of efficiency ratings. The following tabulation lists some typical efficiency ratings for each test and demonstrates the contrast in these rating factors.

Weight Test (percent)	Discoloration Test (percent)	DOP Test (percent)
*	*	99.97
*	90-95	80-85
99	80-85	50-60
96	30-35	20-30
76	8-12	2-5

*Test not practical for more accurate reading.

5.4.1 Types of Air Filters

Air filters may be classified into four general categories, which are:

a. Industrial Filters -- Designed to handle high dust loadings at low airflow rates. This category normally uses a cloth media formed in bags or envelopes with the fabric either natural or synthetic fibers. This type is used primarily in controlling emissions at the source.

   Additional description is found in Paragraph 5.3.1 under "Air Pollution Control Devices" for aerosols.

b. Ventilation Filters -- These filters are applicable to the handling of medium to low dust loadings at high velocities. These may be the self-cleaning type unit, or may be composed of multiple units ranging in face area upwards from 24 by 24 inches, with depths from 2 to 24 inches. This type of filter may be disposable, or may be manually cleanable. Filtration velocities up to 500 fpm are not uncommon, and airflow resistance seldom goes above 0.25 inch WG, and is often less than 0.1 inch WG.

   The filter media in this category includes porous beds of mineral and vegetable fibers, crimped wire mesh, and twisted metal tapes. The dust-catching elements are generally coated with a sticky oil to retain the collected dust particles. These filters are only effective for gross contaminants, and are only to be relied upon to remove about 25 percent of the atmospheric dust, except in areas of very high concentration.

c. Intermediate Efficiency Filters -- Designed to handle low-density dust loadings at filtration rates in the range of 30 to 40 cfm per square foot of filter media face area. Higher airflow capacity is achieved by pleating, or formation of deep pockets. The majority of filters of this type utilize randomly pocketed batts, or blankets of synthetic resin-bonded glass fibers, ranging in thickness from 1/8 to 1/2 inch.

   By varying the diameter of the glass fibers, the thickness of the batt, and the density of the media, wide ranges of dust collecting and holding efficiencies and airflow resistances are possible. The lower efficiency of this type is approximately 35 percent of atmospheric dust by the discoloration test method, with an initial airflow resistance of about 0.2 inch WG. The highest efficiency normally attainable is about 95 percent, using the same discoloration test, with an initial resistance of 0.45 inch WG.

d. High-Efficiency Particulate Air (HEPA) Filters -- These assemblies use a dry fiber filter media in thin porous sheet form consisting of ultrafine fibers usually less than 1 micron in diameter. The filter media is normally pleated or fan-folded to form deep pockets in the assembly, to achieve greater airflow capacity.

This type has a minimum efficiency of 99.97 percent for 0.3-micron particles as determined by the DOP test method at airflows of 20 and 100 percent of the rated flow capacity of the filter. Further description is found in Paragraph 5.4.3.

5.4.2 Selecting Air Filters

Selecting a proper air filter requires an analysis of the requirements for the particular application. The final selection should resolve answers to the questions posed during the analysis, of which the following are but a few and are typical of the factors to be considered:

a. What is the nature of the air to be filtered (i.e., unfiltered industrial or nonindustrial air direct from outside)?

b. What percent will be recirculated?

c. What is the maximum dirt concentration of that air?

d. What is the average particulate size? Weight? Mass?

e. Does the air contain corrosive substances?

f. Does the air possess any unusual characteristics? (Included would be abnormally high, or low, temperature and humidity.)

g. How clean must the air be when it issues from the filter face into the work zone?

h. What is the pressure drop across the filter? (This information will aid in determining the size of the motor and fan, and the power costs for operation.)

i. What is the required face velocity?

j. What funding is required for:

(1) acquisition of the completed facility?

(2) annual maintenance costs?

(3) operating costs?

Many of the above factors are closely interrelated, and a decision affecting any one of the elements may have a direct bearing on one or more of the others. As an example, capacity and pressure are completely inseparable; efficiency and operating costs also bear on the same considerations.

Following the determination of which filter is required, the next step is the preparation of a complete and meaningful filter specification for procurement. It must be sufficiently detailed to assure receiving the exact filter needed, and must be the criteria for receiving inspectors to use as a basis for acceptance. Paragraph 5.12 provides a list of items for inclusion in a specification for filters.

High-efficiency filters are more costly than those having lesser efficiency ratings, and for this reason, it is normal practice to install some form of prefiltration ahead of the more costly and uncleanable filters to increase their service life. The selection of prefilters is a compromise of prefilter efficiency and cost as related to the replacement cost of the final filter. The contention that a more efficient prefilter will improve the efficiency of the final filter is only partially true. The less efficient filter is also less effective for small particles; therefore, the volume of small particles which it will pass will not be materially diminished by increasing the efficiency and cost.

5.4.3 High-Efficiency Particulate Air (HEPA) Filters

The HEPA filter uses a media of dry ultrafine fibers (usually less than 1 micron in diameter), which may be 100-percent glass fiber or a combination of glass and asbestos fibers. This media is formed in a thin porous sheet which is pleated or fan-folded to form pockets, with separators interleaved between the folds to prevent its collapse and to render the maximum area for air filtering. The separators may be made from kraft paper, aluminum, or plastic stock. The media/separator configuration is assembled in a rigid frame. The media surfaces and edges adjacent to the interior sides of the frame are sealed and bonded to the frame with adhesive. The filter frame may be made from:

a. Plain resin-glued plywood

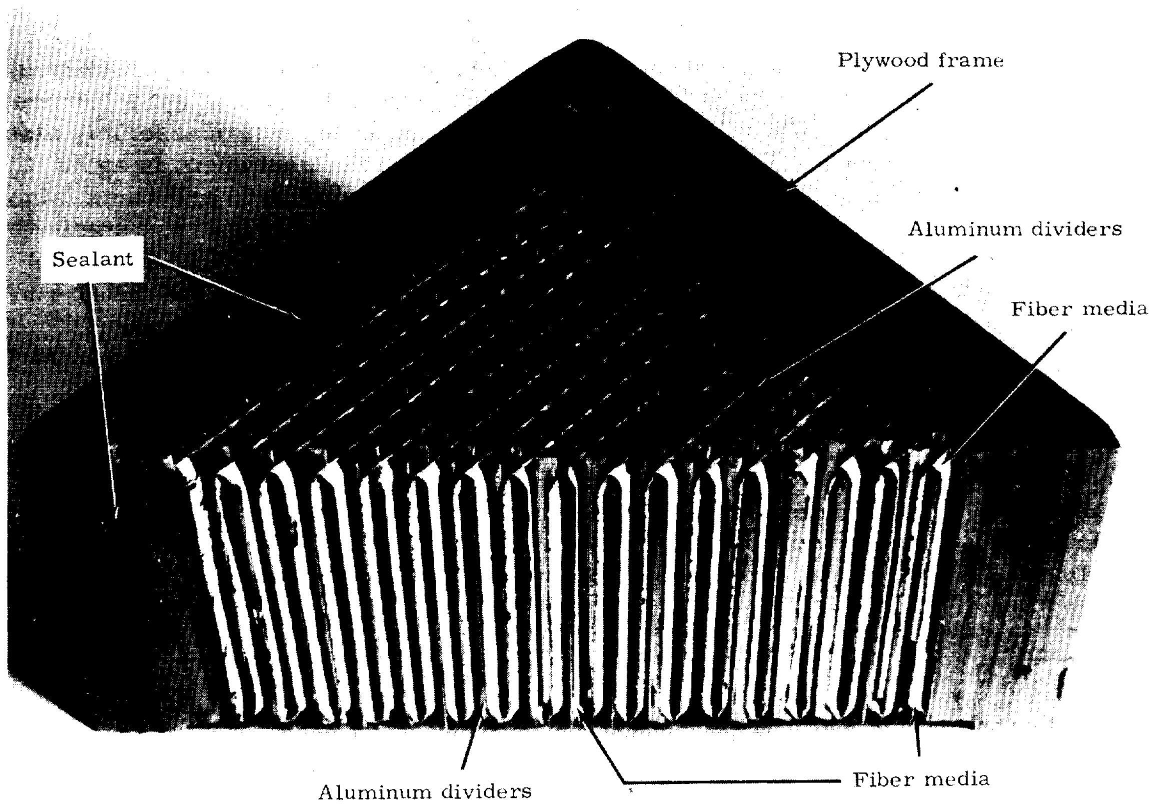
b. Fire retardant-type plywood

c. Metal, either steel or aluminum, with hard nonflaking or nonscaling finish.

The depth of the pockets or folds in the media and the size of the frame determine the filter media area and the airflow capacity of the filter assembly. A standard size filter assembly, 24 x 24 x 5-7/8 inches, will provide a minimum airflow capacity of 500 cubic feet per minute (cfm).

A HEPA media has a minimum efficiency rating of 99.97 percent for 0.3-micron particles, as determined by the DOP test method at airflows of 20 and 100 percent of the rated flow capacity of the filter assembly. This is the only type filter which will provide a supply of air sufficiently free of particulate contaminants to warrant its use for clean rooms and enclosures required to meet the cleanliness levels specified in Federal Standard 209a, Paragraph 5.1.

Figure 5-4 shows a corner section of a typical HEPA filter which has a plywood frame, resilient sealant, 100-percent submicron glass fiber media, and aluminum dividers.



Courtesy of Mine Safety Appliance Company

Figure 5-4. HEPA filter section

The HEPA filter media is critically fragile. It demands great care in handling during monitoring, installing, removing, and repairing. These filters cannot be cleansed of accumulated contaminants; they must be replaced. The outer face in a filter bank installation should always be protected by a protective screen, as a guard against accidental puncturing of the media. This guard may be hardware cloth, stainless-steel open mesh, or expanded metal lath. The finish of the protective material should inhibit scaling, flaking, or corrosion which may be introduced into the work area. When filter units are shipped or stored for any reason, both of the exposed filter faces should be protected with rigid covers, sealed to the filter frame.

The mounting surface of the frame must be flat, within 1/16 inch, and must be made to accommodate a gasket. The gasket material is usually closed-cell, sponge neoprene, and shall be fitted to the mounting surface of the frame so as to preclude any gaps which might permit air leakage around the gasket when it is compressed. This compression, for the purpose of sealing the opening against the passage of air, will cause the gasket to take a ''set'' after an indeterminate time; this is sufficient reason to require a replacement gasket whenever the filter is removed for any reason.

The upstream side of the filter is within the air-supply plenum and is, therefore, under air pressure whenever the facility is operational. When the equipment is turned off, the pressure against the filter is released, and the media/separator assembly also relaxes, causing some minor movement in the media. When the equipment is again turned on, the pressure against the back of the filter is re-established, and some minor media movement again takes place. This movement will quite probably cause some of the fibers to fracture and become loose, and these fragments will be picked up by the airstream passing through the filter. Therefore, it should be standard practice to run any equipment that has been turned off a minimum of 30 minutes before cleansing the filter face guard, the bench tops, or any other surfaces which might be a fallout point for these fibers.

HEPA filters that will meet the exacting requirements for use in clean rooms and enclosures are available if specifications adequately define the requirements and conditions for use. The manufacturer will leak-test the individual filters by the DOP test method, scanning 100 percent of the face area, when specified. This 100-percent scanning test normally costs more, but it provides the user with greater assurance of receiving acceptable filters.

5.5 Nonlaminar Airflow Facilities

The equipment and facilities in this category, commonly referred to as ''conventional'' clean rooms, are characterized by:

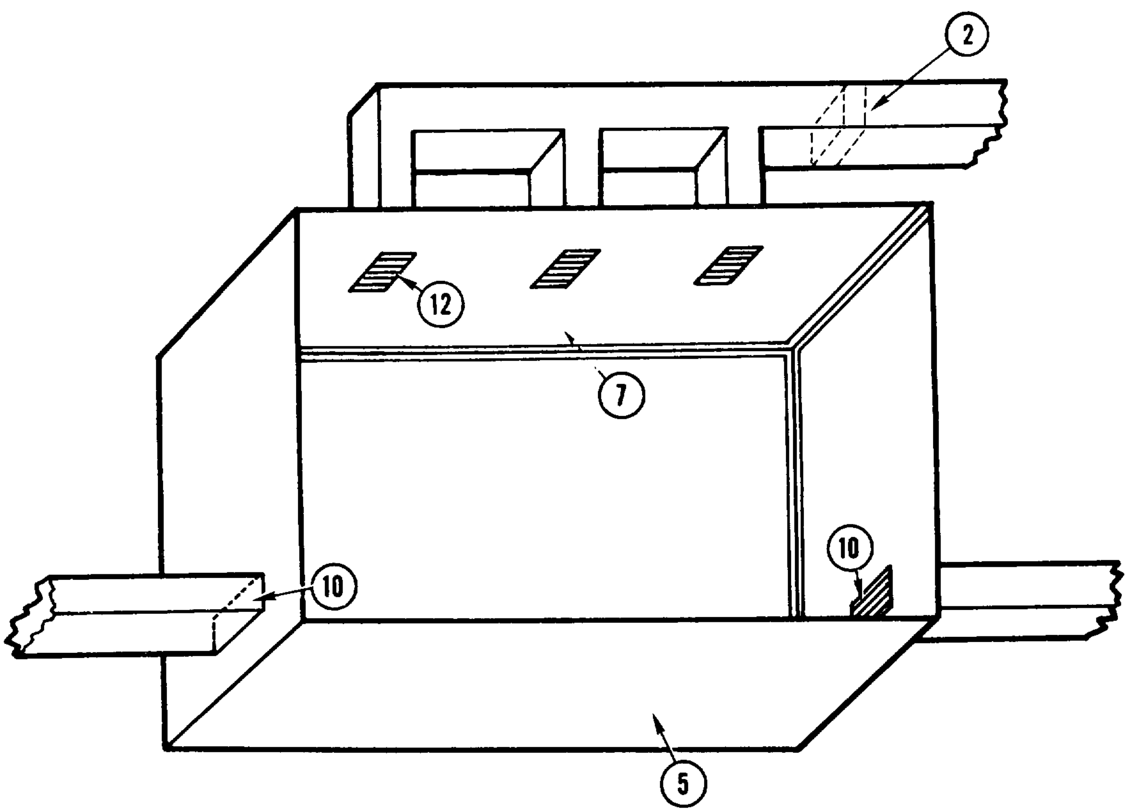
a. An airtight structure into which filtered air is introduced at a predetermined rate

b. The personnel working at or in such an enclosure are completely suited with coveralls, augmented with shoe and full head coverings

c. Constant vacuuming of the area if it is a room, or wiping with non-shedding material if a hood or other enclosure.

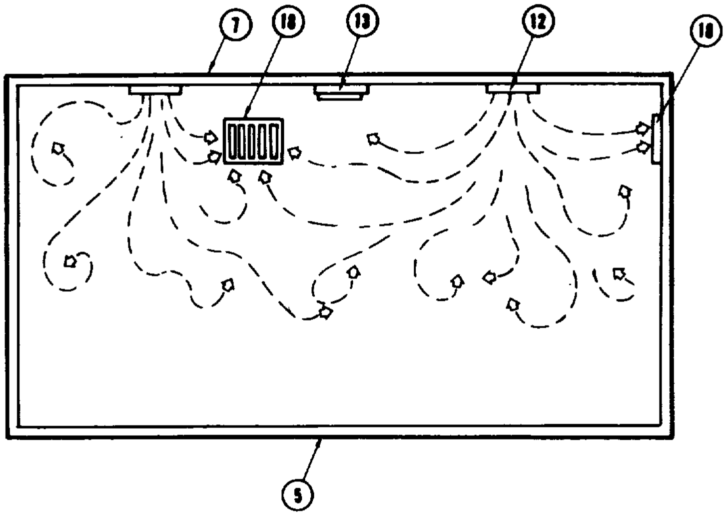
Under this principle, the rate of air change within the enclosure ranges from 15 to 20 changes per hour, through grilled or diffused ducts located in the ceiling, or the upper periphery of the side walls. The size of the enclosure usually dictates the number and capacity of the ducts. The exhaust ports are usually located in the lower periphery of the walls or in the floor itself. Some installations have the exhaust ports in the ceiling or the upper periphery of the walls, which are the least desirable locations. Figure 5-5 is a sketch of typical duct work for a nonlaminar flow clean room. Velocities greater than that required to attain approximately 20 changes of air per hour will cause re-entrainment of particulate matter which has previously settled out of the air within the enclosure. Figures 5-6, 5-7, and 5-8 illustrate the air patterns which will occur due to the locations of the inlet ducts and the exhaust ports. The main danger from such air patterns is that the particulate matter has multiple opportunities to settle on the work piece.

The self-clean-down capability of nonlaminar airflow facilities is quite low, and the time required for contaminants generated within the facility to be exhausted becomes greater as the rate of generation is increased. The best known means of combating this condition is to have a fully garmented janitorial employee vacuuming the room constantly during all working hours. This activity may be lessened somewhat if the occupancy factor is very low in relation to the room area. Care must be exercised, however, to keep the removal of generated contaminants equal to the rate of generation, including that contamination which is carried into the facility by personnel and material. The importance of this cannot be overstressed, because if full control is not maintained, it may be necessary to cease all productive activity within the area for an extended period of time in order to decontaminate and regain control of the area.



2. HEPA FILTERS
5. FLOOR, SOLID
7. CEILING
10. AIR EXHAUST
12. AIR INLET

Figure 5-5. Typical nonlaminar airflow clean room

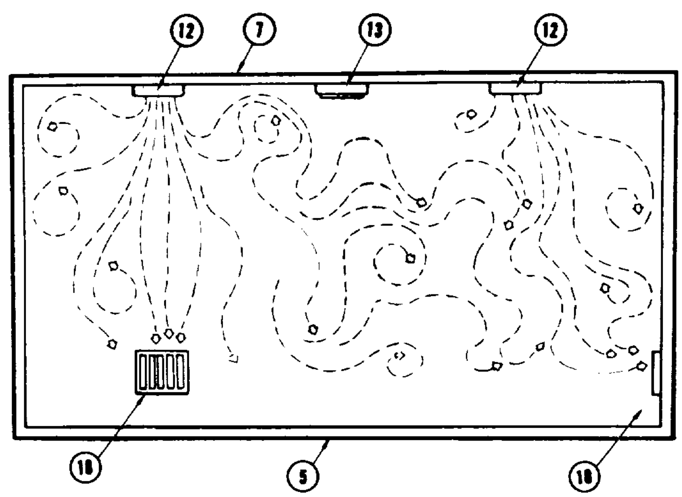


Nonlaminar airflow clean room, in which the air inlet and exhaust ports are located in the upper wall periphery and ceiling.

5. FLOOR, SOLID
7. CEILING
12. AIR INLET
13. LIGHT FIXTURE
18. AIR EXHAUST GRILLE

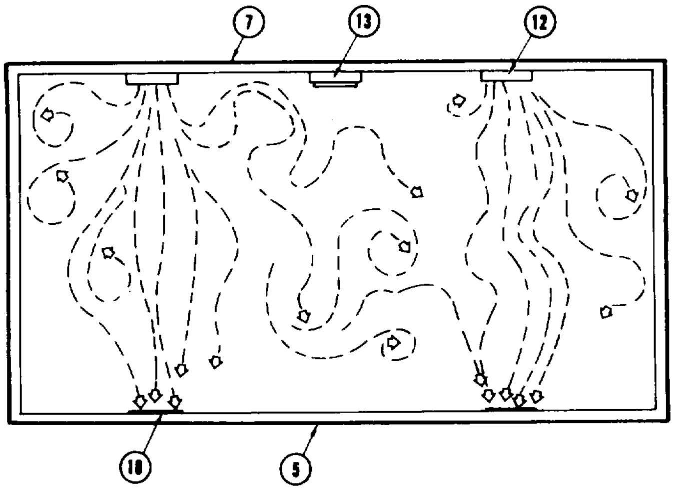
Figure 5-6. Example of random airflow pattern

Nonlaminar airflow clean room, in which the air inlets are located in the ceiling, and the air is exhausted through grilles located in the lower periphery of the walls.



5. FLOOR, SOLID
7. CEILING
12. AIR INLET
13. LIGHT FIXTURE
18. AIR EXHAUST GRILLE

Figure 5-7. Example of random airflow pattern



Nonlaminar airflow clean room, in which the air inlets are located in the ceiling, and the air is exhausted through the floor.

5. FLOOR, SOLID
7. CEILING
12. AIR INLET
13. LIGHT FIXTURE
18. AIR EXHAUST GRILLE

Figure 5-8. Example of random airflow pattern

5.5.1 Nonlaminar Airflow Rooms

Due to the delicate balance between control and lack of control of a nonlaminar airflow facility, there is a need for smooth surfaces and the absence of ledges, crevices, or other projections on which contaminants might lodge (and later be re-entrained in the airstream). It has been standard practice to employ stainless steel for walls and furnishings, with all joints or corners being coved to facilitate the removal of particulate matter. A hard gloss, nonchalking surface is entirely satisfactory, if it is cleaned with a vacuum brush frequently. The structure should be sealed tight enough to preclude the infiltration of dirt, dust, or other material from the outside, and to maintain the built-in slight overpressure. Figure 5-9 displays a typical nonlaminar floor plan.

Lights, if recessed, must be sealed in the same degree that the room itself is sealed. The changing of bulbs or tubes should be possible from the exterior to eliminate the entrance of maintenance personnel and the opening of the light fixture within the area.

Doors should be limited to the extent possible to comply with local codes for available exits, and should be self-sealing in order to maintain the room overpressure. The main personnel door should be a part of an airlock which has the provision that both doors into the airlock cannot be opened simultaneously, and further should be of a size to accommodate only one person at a time.

Air showers should immediately precede the airlock, and to be fully effective must have the capability of removing, by jets of precleaned air, any particulate matter which would normally be sloughed off the person or garment by physical activity. The air jets should be so placed as to completely cover the entire body, from the ankles to the top of the head covering, and should be automatically timed to submit the person to a minimum of 20 seconds of a continuous air shower. The door from the air shower to the nonlaminar airflow room should not release until the interval of air cleaning has been completed.

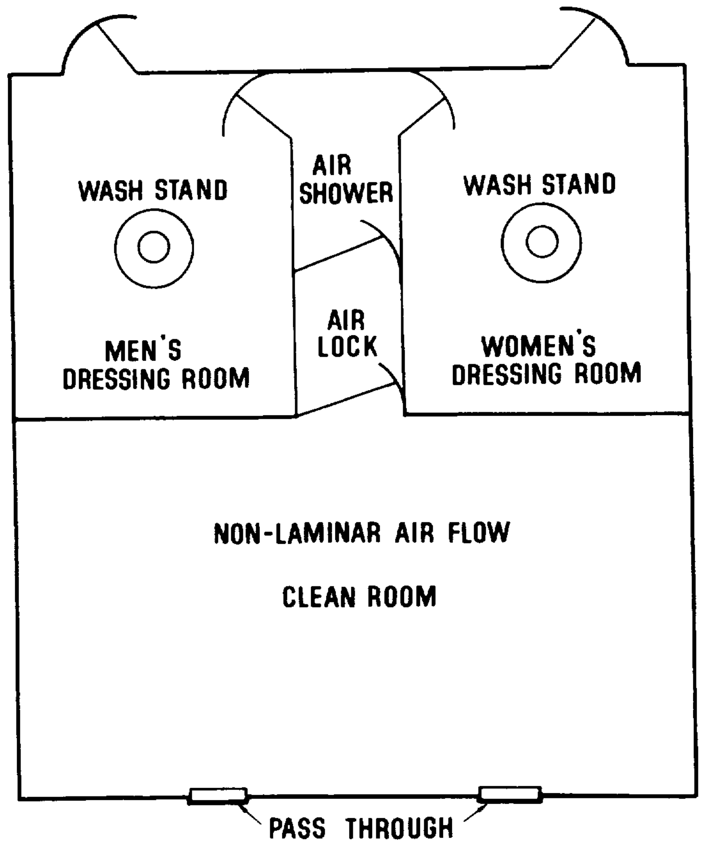


Figure 5-9. Typical floor layout for a nonlaminar airflow clean room

The most effective garment for wear in a nonlaminar airflow room is the coverall, sometimes called a "bunny suit." The best head cover is one that entirely covers the head, hair, and the neck. Shoe covers of material as nonshedding as such an item could be are usually better than rubber-soled canvas shoes, inasmuch as these shoes are not manufactured from nonshedding material, and are prolific sources of generated contamination. Any person entering the facility must be required to wear approved garments.

5.5.2 Nonlaminar Airflow Work Stations

Work stations of this type generally provide a clean atmosphere in the neighborhood of Class 100,000, and in some instances can achieve a Class 10,000 if strict operating procedures are observed.

Many clean bench operations are those in which the equipment is itself physically located within a clean room, and the bench is intended to supply a somewhat higher degree of cleanliness required for an operation or series of operations. A single clean work station (or a line of them) may be located in an uncontrolled area, and the operation performed within the confines of the work station may be assured of seeing the minimum contamination that the work station is capable of delivering. The major problem is getting the product into the hood in a clean condition, so that it is not contaminated during transport through the uncontrolled area. Unless this problem is solved, or cleaning is the first operation performed in the work station, this will not be a worthwhile installation.

5.5.3 Fume Hoods

A fume hood is basically an enclosure with ventilation achieved by a duct to the outside atmosphere and air movement provided by a fan or blower. Other features may include interior illumination, sliding sashes, sinks, services, and baffles to improve airflow characteristics.

Fume hoods are designed to confine and discharge to the atmosphere odiferous and toxic materials in the form of fumes, gases, vapors, and particulate dispersions. While performing this function, they are designed to provide protection to laboratory personnel from harmful and dangerous materials. Secondary considerations include the confinement of spills and splashes, reduction of cross contamination, and the removal of heat and humidity generated by laboratory activities.

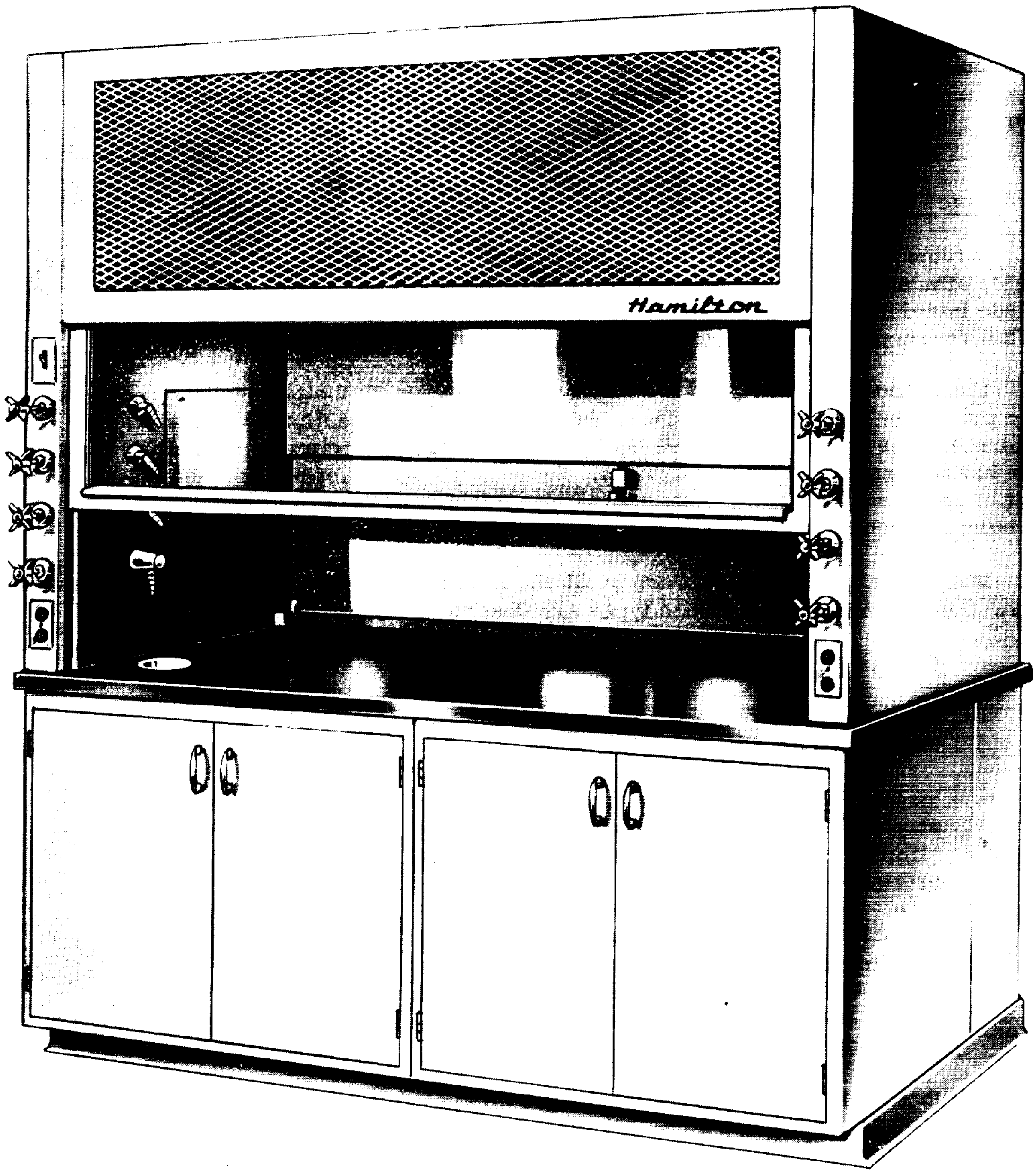
Many types of fume hoods are available in standard and special design configurations. Some of the more common types are described below:

a. Conventional Hood -- A cubical enclosure vented through adjustable slots at the top and bottom of the rear wall. A source of illumination, usually a fluorescent light, is included in the assembly which may or may not be furnished with a movable sash.

b. Streamlined Entrance Hood -- This hood incorporates a smoothly streamlined entrance to provide a reduced face velocity. The elimination of corner posts, offsets, and irregular configurations promotes a uniform flow of air moving smoothly through the hood face. For low hazard operation, velocities as low as 50 feet per minute have proved to be adequate. In other cases, velocities ranging upwards to 125 feet per minute were required to prevent spill-out of heavier-than-air gases and to eliminate counter flow caused by installed apparatus. An example of this type of hood is shown in Figure 5-10.

c. Bypass Hood -- This hood provides an air bypass feature when the sash is in a closed or nearly closed position, thereby preventing a "starved" condition for the blowers.

d. Balanced or Compensating Hood -- This type of hood is designed to induce untempered outdoor air into the hood entrance area, mix it with tempered room air, and pass it into the hood opening. This type is preferred for use in air-conditioned rooms, since it does not put an excessive, additional load on the air-conditioning system.



Courtesy of Hamilton Manufacturing Company

Figure 5-10. Typical fume hood

Caution should be exercised in the proper location and use of fume hoods. Failure to observe the following rules can greatly reduce performance and effectiveness.

a. Never locate a fume hood adjacent to a doorway, open window, exhaust ventilating grille, or an often-used aisle. Air disturbances from such features can cause spill-out of hazardous fumes and materials.

b. Do not install large and bulky apparatus near the face of the access opening.

c. Locate apparatus within the hood so that it is not too near the hood entrance and does not obstruct proper airflow.

d. Instruct operating personnel in the proper use of fume hoods and associated equipment.

e. Institute a periodic inspection and maintenance program. Always retest performance after changes in room layout, ventilating and air-conditioning systems, or building structure.

f. Emission of large quantities of toxic, poisonous, or pathogenic materials to the outside atmosphere may call for the use of special filtering or washing apparatus prior to release. See Paragraph 5.3.

5.6 Laminar Airflow Facilities

The laminar airflow concept came into being as a practical and highly efficient means of maintaining a low particle count in a controlled area. It is most aptly defined as "airflow in which the entire body of air within a confined area moves with uniform velocity along parallel lines." Unlike the nonlaminar airflow which has random flow characteristics, the laminar airflow concept offers a choice of both vertical and horizontal airflow directions, accompanied by a broad range of air velocities to suit the operational and product needs. From tests conducted in the laboratory and observations of operating facilities, it is recommended that vertical laminar airflow rooms not be operated below 65 lineal feet per minute, with the normal air velocity being 90 ± 5 lineal feet per minute. Horizontal facilities will require air velocities from 100 fpm for installations up to 25 feet in length, to speeds ranging from 125 to 140 fpm for facilities of greater length.

Laminar airflow facilities will provide a clean atmosphere but will not clean a part or components. The advantages and disadvantages of laminar airflow facilities are enumerated in Table 5-11, with clarifying explanations for each.

The various types of laminar airflow facilities are discussed and conceptually illustrated in subsequent paragraphs.

TABLE 5-11

Laminar Airflow Facilities
Advantages and Disadvantages

Advantages	Reason
Clean-down capability	The air velocities are sufficient to carry away contamination generated or carried into the facility. At 90 feet per minute air velocity, a vertical laminar airflow room with a 10-foot ceiling would undergo a complete change of air in less than 7 seconds.
Any particle will "see" the product only once	Any particle capable of being airborne will be carried away from the product by the airstream, because of the laminar fashion in which the air pattern behaves.
Reduced maintenance	The ability of the facility to exhaust the airborne contamination produced within the installation precludes the need to continuously vacuum the area in an effort to maintain the desired levels of airborne particulate.
Class 100 available	Vertical laminar airflow facilities are fully capable of attaining a Class 100 condition, and with intelligent personnel direction, will maintain this class, or better.
Better control of humidity and temperature tolerances	The volume of air introduced into the area is so much greater than other types of environmentally controlled equipment, that the absorption of heat, cold, moisture, or dryness is distributed over a greater volume of air, which greatly simplifies the maintenance of the desired levels. The recirculated portion of the air is also less costly to recondition because it has deviated from the norm much less than if it remained in the room for a longer period.
Reduced garmenting restrictions	In a majority of circumstances, garmenting requirements may be met by a smock and head covering, due in large part to the capability of the laminar airflow to carry away particulate matter emitted by the worker. This represents a sizeable savings in manhours consumed in the robing and disrobing several times each day when all-encompassing-type garments are required. The additional freedom of movement frequently manifests itself in improved output.
Elimination of air locks, air showers, and large dressing rooms	Except in unusual cases (microbial or sterile conditions), air showers, double door airlocks, and large dressing rooms are not usually an item to be considered for use with a laminar airflow installation.

TABLE 5-11
(continued)

Disadvantages	Reasons
Increased volume of air required	The higher air velocity requires larger fans, motors, and ducts. The quantity of makeup air may be as low as 5%, depending on the occupancy and production of gases and odors. More than 10% makeup air would be unusual.
Vertical rooms require more vertical clearance	The floor and ceiling plenums of vertical rooms require 4 to 6 feet in vertical height. This must be added to the clean room ceiling height to determine the total vertical clearance needed within the structure in which the clean room is located. The exact extra height is dependent on such factors as room size which influences plenum depth, the type, location and size of the return ducting, and the stipulated air velocity for the room.
Original cost	In the light of an initial outlay of capital, a vertical laminar airflow installation will cost a bit more than other types of equipment. On the other hand, the VLF offers better control of contamination, and at a considerable reduction in the maintenance outlay.
	When considering a horizontal laminar airflow facility, the cost will likely be less than competitive types of facilities, with improved performance.

5.6.1 Vertical Laminar Airflow (VLF) Rooms

A VLF room employs the basic laminar airflow principle with the air flowing vertically from the ceiling filter bank through the floor grating as shown in Figure 5-11. A typical VLF clean room is shown in Figure 5-12. Some of the basic design requirements for a VLF room are listed in Table 5-12.

A properly designed VLF clean room provides the following advantages over other types of clean rooms:

a. Will operate well within the Class 100 level

b. Operates effectively within a wide range of air velocities

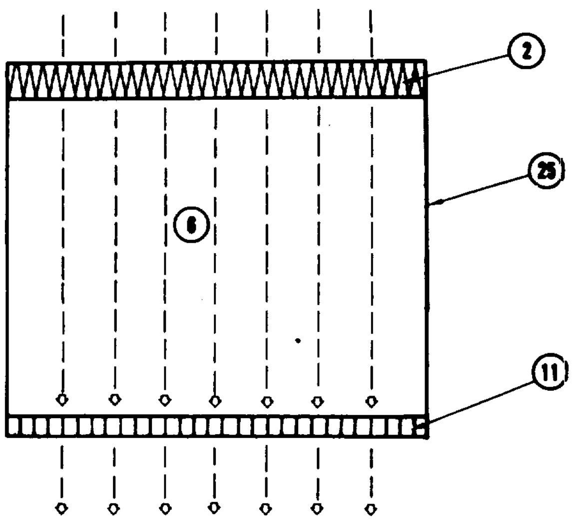
c. Provides a rapid removal of generated or introduced contaminants from the room

d. Reduces cross-contamination between adjacent operations

e. Substantially reduces janitorial and maintenance costs

f. Minimizes the effects of personnel emissions on critical operations

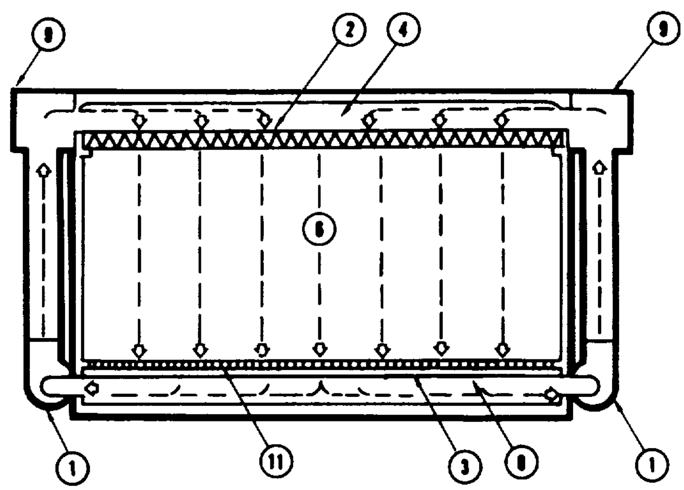
g. Proves less expensive to operate and maintain if calculated on a long-term basis.



2. HEPA FILTERS
6. AIRFLOW
11. FLOOR, GRATED OR PERFORATED
25. ROOM WALL

Figure 5-11.
Basic laminar airflow concept

Figure 5-12.
Vertical laminar airflow clean room



1. BLOWER
2. HEPA FILTERS
3. PREFILTER
4. SUPPLY PLENUM
6. AIRFLOW
8. EXHAUST PLENUM
9. SUBPLENUM
11. FLOOR, GRATED OR PERFORATE

TABLE 5-12

VLF Room Requirements

Item	Requirements
Ceiling	Composed entirely of the supporting framework and verified, leak-free HEPA filters. The filter seal around the periphery of each HEPA filter should be verified to be free from leaks. Any opening in the HEPA filter holding frame, such as sprinkler heads, lights, or electrical conduit, should also be verified to be free of leaks.
Floor	The entire area (mounting bases for stationary equipment may be excluded) should serve as an air exhaust, and should be of grating or perforated metal, which should be at least 60% open for the passage of air. In instances where the floor openings are used to balance the airflow within the room, the percentage of opening may vary from point to point within the room.
Walls	Normal construction materials are satisfactory if the chosen materials are firmly affixed to supporting members, and all joints are sealed. The interior surface of the selected material should have a hard, gloss finish. It is very desirable to eliminate uneven contours and any strips or ledges, for they will create eddies and turbulance adjacent to the wall. Any wall surface will create a small amount of drag, thus the placement of the effective edge of the HEPA filter should be situated as close to the inner surface of the wall as is feasible.
Plenum	Both the upper (behind the HEPA filters) and lower (under the grated floor) plenums should be of sufficient depth to promote the proper distribution of the air. Very shallow plenums may induce "dead" spots within the plenum, and will create low-velocity areas within the room directly below the spot or zone. This condition will reduce the overall efficiency of the room, and can be responsible for cross-contamination between operations within the room, which is a condition that should not occur in a VLF facility.
Return air ducts	Ducts should be of sufficient size to permit the flow of return air to the supply plenum at a velocity which will not create noise or vibration.
Air velocity	To attain a Class 100 condition within a VLF room, a lineal air velocity issuing from the face of the HEPA, and measured 12 inches from the filter, should fall within the range of 90 ± 10 ft/min. Deviations outside of this range would indicate an unbalance in the plenum, or if the velocity is very low, there may be a filter stoppage. Velocities below the recommended mean will reduce the efficiency of the room to a point that, below 65 fpm, will generally nullify the laminar airflow concept. Velocities in excess of 100 fpm are considered unnecessary, except under abnormal conditions, or when the occupancy rate of the room is exceedingly high.
Construction	The general construction requirements for the VLF room should include the specification that it be capable of maintaining a minimum of 0.05 in. WG. If temperature and humidity limits are imposed, the room should comply with the tolerances stated, plus a normal safety factor.
Airlocks air showers	Except when the VLF room is to be employed in the control of microbial or sterile conditions, the use of these adjuncts is considered to be unnecessary.
Shoe cleaners	This equipment is usually not needed, because vertical laminar airflow, plus gravity, plus the grated or perforated floor will amply remove any dirt within reasonable limits. If the location is such that the employees bring in surplus amounts of dirt on their shoes, the use of a multiple brush/vacuum system should be considered.

5.6.2 Vertical Laminar Airflow (VLF) Portable Curtain Units

This configuration is an adaptation of the VLF room, and provides the capability of enveloping heavy, cumbersome components or structures without resorting to costly crane and forklift operations which would be required to transport the product to a standard clean room. The curtained units will provide Class 100 conditions, which entitles them to justly be named as portable clean rooms.

The curtained vertical laminar airflow facility is fundamentally the same as the VLF room having:

a. Nonstatic plastic curtain side walls extending to within 12 inches of the floor

b. Its own blowers and motors, only requiring electric power

c. A HEPA filter bank

d. Support legs (no height restriction commensurate with proper balance) with locking casters for easy lateral movement

e. 30-second clean-down time

f. Unrestricted entrance through overlapping, weighted bottom flaps on any or all four sides

g. Its own illumination, augmented by light through the transparent curtains.

The portable curtained unit may be used out of doors when the wind velocity is 10 to 20 mph or less. The work level should be not less than 18 inches above the bottom of the curtain walls. Care should be exercised to avoid the rise of dirt from the floor, and the use of compressed air blowoff hoses should be confined to that period immediately after the unit is moved over the structure, to be followed by a wait of a minute or so for the airborne contaminants to be carried away.

If the portable curtained unit is not in constant use and has frequent shutdown periods of more than a minute or so, it should have an opportunity to purge itself for about 5 minutes prior to use. If the inactive periods are in excess of 4 hours, the clean-down time should be 30 minutes and should be accompanied by a vacuuming of the interior of the curtain walls during the clean-down time.

These facilities may be equipped with lift rings at the four corners, which would permit sling lifting by a traveling crane for rapid travel to remote parts of a large manufacturing complex.

Figure 5-13 illustrates the basic design of a curtained vertical laminar airflow unit.

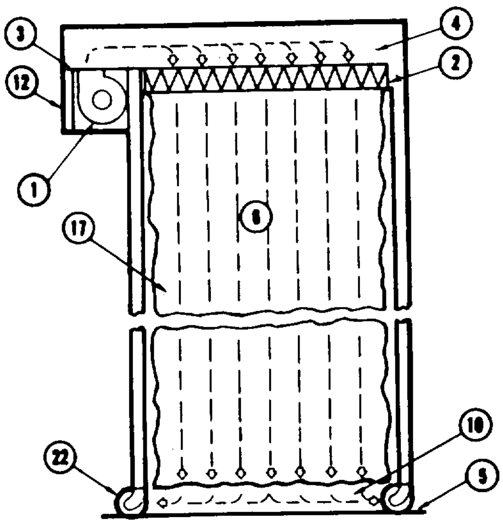


Figure 5-13.

Portable vertical laminar airflow curtain unit

5.6.3 Vertical Laminar Airflow (VLF) Work Stations (Benches)

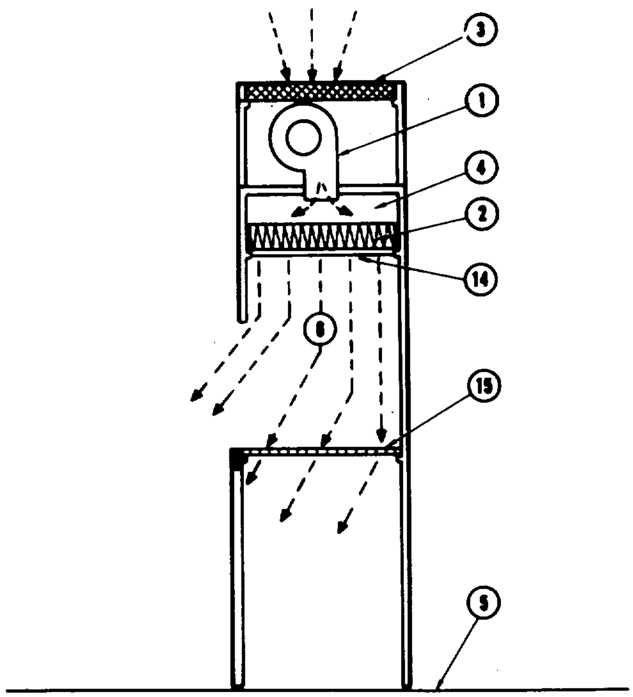
This configuration is also an adaptation of the VLF concept. It too is an outgrowth of the original laminar airflow work station in which the filtered air flows horizontally across the work surface, toward the operator.

The VLF work stations, in general use today, utilize a perforated metal work surface, with the open area ranging from a low of about 30 percent up to about 60 percent. These facilities have work areas ranging from 22 to 30 inches deep and 6 to 12 feet long. Air velocities range from 65 fpm to about 145 fpm. See Figure 5-14.

Some VLF work stations are being offered which contain a series of slots along the work surface for the passage of the air, and a few have an open area along the rear of the work surface with the front open (as is the case with all these stations). Some also have removable work benches, with the motor/blower, filter and plenum unit standing on legs, not unlike the curtained unit without casters.

The VLF work station has many advantages in a general way over the horizontal work station (Paragraph 5.6.6), but it must be evaluated in relation to the type of operation to be performed in determining which is the best.

The VLF work station has the capability of operating well within the range of Class 100, but this should not be the reason for permitting lax worker habits.



1. BLOWER
2. HEPA FILTERS
3. PREFILTER
4. SUPPLY PLENUM
5. FLOOR, SOLID
6. AIRFLOW
14. PROTECTIVE SCREEN
15. GRATING WORK SURFACE

Figure 5-14.

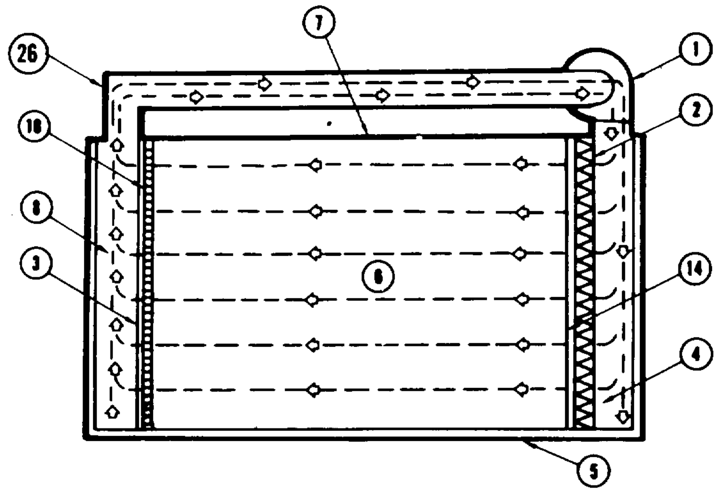
Typical vertical laminar airflow work station (bench)

5.6.4 Horizontal Laminar Airflow (HLF) Rooms

This facility differs from the vertical laminar airflow in the direction of the air travel. In an HLF room, the HEPA filter bank comprises one entire wall, and the opposite wall becomes a grilled or louvered exhaust area, which causes the air to move in a horizontal manner. Both the supply and exhaust walls are backed by plenums for dispersing and balancing of the introduced air.

The exhausted air is returned to the supply plenum via special ducts, or the use of the space above the room ceiling serves as a duct. The interior of this space should be sealed and free of chalking, shedding, or contaminating material of any kind, to preclude early replacement of HEPA filters. If the area above the room is not available, similar use may be made of a space under the floor, or along one wall in which no openings or obstructions are required. Figure 5-15 illustrates an over-the-ceiling duct installation, which may be altered to suit an existing structure.

Horizontal rooms cannot be characterized as being of any one class, 100 or 10,000, or even 100,000; they will always be "zoned" rooms. The first operating position directly in front of the HEPA filter bank will be Class 100; the remaining operating positions within the room will vary from Class 100 to a figure equal to the amount of contamination emitted and generated by the prior operation. To establish the zones as they actually exist, it is necessary to use a particle counter immediately downstream from each operation to establish the quantity of particulate matter that is released by the operator and the operation.



1. BLOWER
2. HEPA FILTERS
3. PREFILTER
4. SUPPLY PLENUM
5. FLOOR, SOLID
6. AIRFLOW
7. CEILING
8. EXHAUST PLENUM
14. PROTECTIVE SCREEN
18. AIR EXHAUST GRILLE
26. RETURN DUCT

Figure 5-15. Typical horizontal laminar airflow clean room

The HLF room will usually cost somewhat less than a VLF facility of the same square area, and this variation increases as the length of the room becomes greater. It is normal to utilize the narrow dimension of a room for the HEPA filter bank to be installed, simply as a means of reducing the number of HEPA filters required. In a VLF room, this is not a consideration. However, the requirements for a product may dictate that the longer dimensions be the HEPA filter bank, in which case the cost of the HLF room will come closer to that of the VLF room.

Ceiling height in any laminar airflow facility need only be adequate to accommodate the equipment and to prevent a feeling of being caged on the part of the workers. The architectural practice of requiring a given number of cubic feet of space for each employee to ensure adequate ventilation is unnecessary in a laminar airflow room, VLF or HLF, simply because the greater air change rate in the facility takes care of the need for reserve quantities of air.

Air velocities in HLF facilities are usually somewhat higher than in VLF rooms because:

a. The air travels a greater distance and must therefore have a somewhat higher velocity to ensure that the particulate matter which becomes airborne will remain in the airstream until it is exhausted.

b. The obstructions above the work level become a factor when the air travel is horizontal.

The minimum velocity recommended for a relatively short room would be 100 fpm, and increases up to 140 fpm are not unusual for longer rooms, or those with a high density of obstructions or people.

Equipment and work station placement within an HLF room is important, because the generation from one operation will directly affect the operation immediately downstream from the first position. If appropriate, staggering of the work positions is suggested. It is strongly recommended that the high contaminant-producing operations be placed at the exhaust end of the room, with less contaminate-producing work progressing towards the front, or HEPA filter bank end of the room.

Horizontal laminar airflow rooms have a capacity for rapid clean-down, but they do require more attention to the personnel working within the room, and somewhat stricter discipline. Garmenting is important, but unless work is being done below 30 inches from the floor, it is necessary to employ only smocks and head coverings.

5.6.5 Horizontal Laminar Airflow (HLF) Tunnel

Horizontal laminar airflow facilities all predicate their effectiveness on what might be termed a "low-speed wind tunnel." The theory has been adequately verified by many installations, which reflect several variations of the original HLF room. One of the most successful and widely used of these variations is the HLF open-end tunnel.

The HLF tunnel differs from an HLF room in the following details:

a. The tunnel is always erected within another building of some kind, whereas the HLF room may well be an independent structure.

b. The tunnel air supply is normally taken from the surrounding atmosphere, instead of originating from a separate source or from the main plant duct system, as is the usual practice with HLF rooms.

c. The exhausted air from the tunnel is released into the surrounding space, while an HLF room recirculates at least 75 percent of the air exhausted from the room.

d. No positive pressure is maintained in a tunnel, which relies upon the air velocity to overcome infiltration upstream into the tunnel. A slight overpressure is always maintained in an HLF room.

e. The temperature and humidity in an HLF tunnel is limited to that established within the surrounding area.

f. An HLF tunnel structure is usually composed of:

(1) a series of laminar airflow modules firmly affixed together

(2) an open framework of angle iron or pipe, to form the basis for the walls and ceiling

(3) material such as vinyl sheeting, or pieces of rigid plastic, to be draped over or affixed to the framework to form the walls and ceiling.

g. Light from the existing permanent illumination system will penetrate through the transparent ceiling and walls, which may be augmented by bench or auxiliary lighting.

h. Air velocities slightly in excess of the recommended air speed for an HLF room will be required, but the actual velocity will be determined by the degree of air cleanliness needed and the occupancy and process characteristics.

Figure 5-16 illustrates the HLF tunnel, which is the least expensive of all laminar airflow installations, or any other kind of clean room facility. An open-end, laminar airflow tunnel will provide Class 100 at the first work position downstream from the HEPA filter bank. Classes of succeeding positions are determined by the volume of contaminants generated by the preceding upstream operations. An HLF open-end tunnel offers the following benefits:

a. Rapid clean-down

b. The lowest cost per square foot attainable

c. Although not a portable installation, the cost of moving to another location is minimal

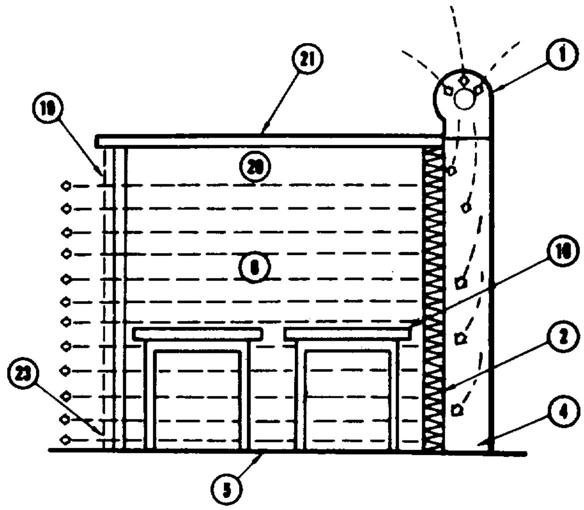
d. Simple to either enlarge, or to reduce in length

e. Very low maintenance cost.

5.6.6 Horizontal Laminar Airflow (HLF) Work Stations (Benches)

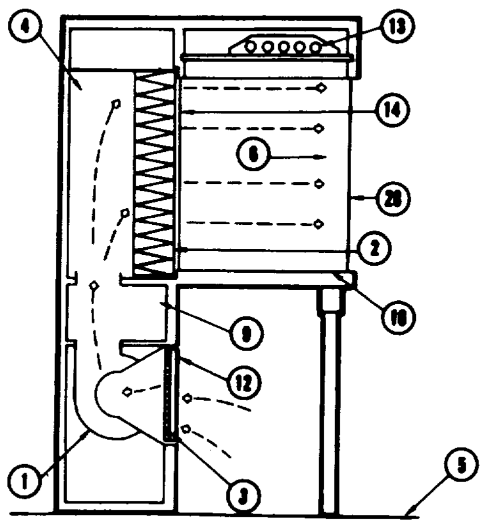
The horizontal laminar airflow work station, or bench, provides the opportunity to establish a localized clean "zone" for bench-type operations. This type of equipment is illustrated in Figure 5-17. Many variations of this basic model are in common use. One such variation involves the air intake and motor/blower located above the plenum and light hood, which is advantageous when the bench is to be located on concrete flooring in climates having cold and damp weather extremes. The efficiency of a bench is influenced more by good engineering practice and an understanding of airflow principles than by the use of a particular model or style of bench.

The HLF bench has the capability of providing Class 100 cleanliness under operating conditions, within the confines of the work area when the air velocity is 90 ± 5 ft/min., and laminar airflow characteristics predominate throughout the entire work space, with a minimum of eddies.



1. BLOWER
2. HEPA FILTERS
4. SUPPLY PLENUM
5. FLOOR, SOLID
6. AIRFLOW
16. WORK SURFACE
19. OPEN END
20. ENCLOSURE
21. FILM OR RIGID CEILING AND WALLS
23. CEILING AND WALL SUPPORT

Figure 5-16. Horizontal laminar airflow tunnel



1. BLOWER
2. HEPA FILTERS
3. PREFILTER
4. SUPPLY PLENUM
5. FLOOR, SOLID
6. AIRFLOW
9. SUBPLENUM
12. AIR INLET
13. LIGHT FIXTURE
14. PROTECTIVE SCREEN
16. WORK SURFACE
28. END PANEL

Figure 5-17. Horizontal laminar airflow work station (bench)

Several factors which govern the capability of the work station to provide laminar airflow characteristics with a minimum of eddies are:

a. The distance from the effective edge of the HEPA filter to the work surface, end panels, and top. The effective edge of a HEPA filter is defined as the juncture of freely functioning filter area with the sealant joining the filter to the filter frame. The bench work surfaces, side panels, and top must be flush with and at right angles to the effective edge. This is necessary for laminar airflow and will prevent outside air from being drawn into the bench along the enclosure walls. The importance of this facet of proper design of an HLF work station (bench) cannot be overstressed and should be a part of the specifications for the purchase of any equipment of this type.

b. Consistent velocity of 90 ± 5 ft/min. across the complete face of the output side of the HEPA filters. The filters must be free of leaks, both in the filter media and around the edges of the filter frame.

   An improperly engineered bench may drive the air into the output plenum immediately adjacent to the rear face of the filter, at a velocity which would actually draw air from the bench work through the HEPA filter (in the reverse direction) into the plenum. If very low velocities are registered at or near the edges of the filter, it is advisable to investigate the cause, or if a new purchase, to reject if it does not meet specifications.

c. Side panels (stationary or removable) tight enough to prevent unfiltered air being drawn into the work area from the outside. The majority of benches are made with removable glass or transparent plastic side panels in a channeled receptacle, in the event that the bench is to become a part of a progressive assembly line and the end panel is not wanted. It would be well to test the seal at this point to determine that no air is being drawn into the work area. The purchase specification should stipulate that no air should leak around the end panels.

The use of HLF work stations (benches) should be viewed as auxiliary equipment rather than a permanent installation under long-range conditions. However, these pieces of equipment, in their wide range of sizes and shapes, have many attributes, such as:

a. Rapid self-clean-down capability (the work surface must be manually cleaned; the airstream will not clean it).

b. Ready access to the work area through the open front.

c. Minimal personnel restrictions, although training in the allowable and nonallowable practices should be provided.

d. Portable; this equipment may be purchased with, or without casters, and some manufacturers make casters standard equipment. In addition, the great majority are made to pass through a 30-inch door with very little adjustment. Unless ordered otherwise, most of them are equipped for 120-volt electric power and have reasonable length cords supplied.

e. Adaptable to the creation of a progressive assembly line for the production of components under clean atmospheric conditions. The end panels may be removed (as noted above), and the space between the benches sealed to preclude the infiltration of unfiltered air. These installations need not be in a controlled atmosphere, but may even be set up and successfully operated in a machine shop or other high contaminant generating area.

If an existing clean room is inadequate for the needs of newer and more sophisticated components and systems, it is feasible to upgrade such an area by the use of HLF (or VLF) work stations. The area involved will play an important part in any determination to make such a move, but with normal ceiling heights, it is possible to attain a Class 100,000 room by the placement of this type of equipment covering approximately 25 percent of the square area of the room. A rule of thumb to use in figuring the volume of benches to be used for this purpose is that for each lineal foot of bench, 2-1/2 square feet of floor space is required. For example, a 10 by 10 foot square room would require 25 percent of 100 square feet, or 25 square feet, and applying the rule of thumb, 10 lineal feet of HLF work station would be required, which could be increased to 12 lineal feet of bench by the use of two 6-foot benches. To maintain the improved cleanliness condition, at least one of the two benches should be operational around the clock during nonworking hours.

5.6.7 Balanced Laminar Airflow Hood

The balanced laminar airflow hood was developed to provide an open access fume controlled area and still retain the characteristics and advantages of laminar airflow. It functions as a safe space for working with toxic fumes and offers a method of controlling the dissemination of unwanted odors.

The device operates on the basis of "push-pull": one motor/blower pumps the air through a HEPA filter into the work area, and a second motor/blower exerts a suction and draws the air from the work area and exhausts it through a duct system. The balance is accomplished by means of a damper, located in the exhaust duct, which will compensate for any difference in the motor speeds. It is this balance which allows the device to be operated with an open front for ready access, without siphoning any room air into the work area, or conversely, spilling any of the contaminated air into the room space.

The entrance, or withdrawal, of a work piece having large mass should not upset the balance for more than a fraction of a second or so. The device should be balanced to accommodate the operator's arms going in and out the number of times that the specific operation will require. It is normal, when dealing with toxic fumes, to adjust the damper to draw a very slight amount of room air into the hood work area, and to keep the adjustable sliding glass sash at the lowest convenient level and still maintain ready access. Figure 5-18 illustrates a typical design for a balanced laminar airflow hood.

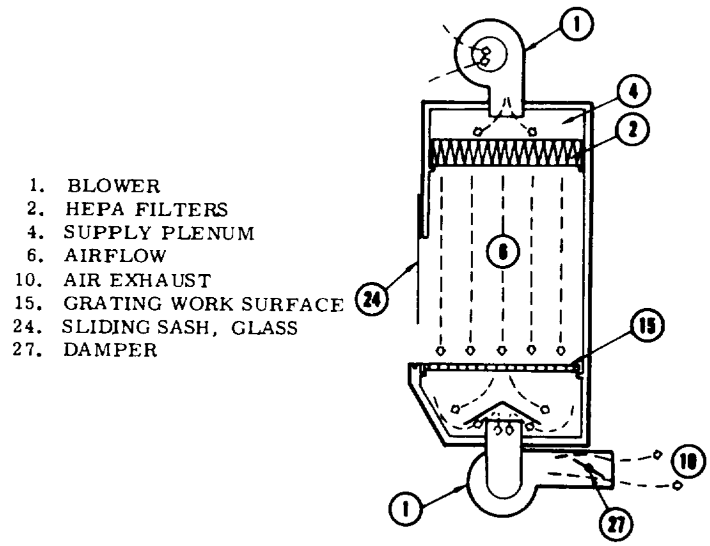


Figure 5-18. Balanced laminar airflow hood

Basic design considerations for the development or specification of this device should include:

a. A HEPA filtered air supply from a blower/motor, having the capacity to deliver 90 ± 10 ft/min.

b. A confined work area with an adjustable sliding glass sash, such that the vertical interior surfaces are flush with the effective edge of the HEPA filters.

c. A perforated (or grated) work surface.

d. An exhaust motor/blower and exhaust duct and vent. The motor/ blower must have the capability of removing as much air as might be introduced from the supply source.

e. A balancing damper located in the exhaust system.

Selecting and specifying the exact configuration for a device of this type will be governed by the needs of the product or process employed. There are several standard variations currently available which may be generally described:

a. Typical balanced laminar airflow hood (Figure 5-18).

b. Same as "a" except having HEPA filters for the exhausted air.

c. Recirculating hood, for use when toxicity and odors are no problem, but when extremely high levels of control are required.

d. Same as "a" except with provision for a tank, sink, or other equipment needed within the controlled area for use with toxic materials.

The devices are generally not stock items with the majority of manufacturers, due to the vast number of sizes and conditions which might be specified. Within the realm of reason, any size desired could conceivably be fabricated. However, careful consideration of the requirements and specifications is required to assure proper operation for the particular application.

5.7 Temperature and Humidity in Clean Room Facilities

The selection of temperature and humidity limits is both product and personnel oriented. The best conditions for the product are major considerations, but if these conditions are uncomfortable or annoying to the personnel, some compromise may be possible in some instances.

Geographic location will obviously impart some influence on the final selection, because the adding or removal of heat in areas of wide temperature extremes is an important cost item. Maintaining certain humidity ranges can be equally expensive.

The amount of makeup air is an element which also must be considered, so the decision is not only one of temperature and humidity but also of the degree of change and the gross volume.

The cubic volume of air requiring treatment for a nonlaminar airflow facility will be approximately 25 percent of that necessary for a laminar airflow installation of comparable size. However, the dwell time of the air in the nonlaminar room is at least three times greater than in a laminar-type room. The reduced dwell time will be reflected in a smaller temperature and humidity variation because the exposure to heat gain or loss is appreciably reduced. It is true that a larger volume of air will be passed through the treatment area, but it will require less power to return it to its stipulated level.

All sources of heat must be considered in calculating the cooling capacity needed for the facility. Two sources that are sometimes overlooked in clean room design are: (a) the heat generated by the motor/blower operation, and (b) the heat released by moving air, which was originally in the form of energy imparted to the air by the blower. Other sources such as people in the room and heat-generating operations must also be considered.

5.7.1 Temperature

Temperature control in clean room areas should be adequate to maintain a nominal temperature of 72°F, except for those laboratory or work areas where different temperatures are necessary for product stability, in which event the required temperature should be specified. The range of temperature variation required at the control point may be ±0.25°F in the most critical areas and ±5.0°F in normal clean room areas.

5.7.2 Temperature Monitoring

Temperature monitoring should be accomplished by conventional devices, the simplest and most accurate being a calibrated Fahrenheit thermometer. Automated devices also may be employed, but they should be checked against the thermometer at least once each 24 hours.

If nonrecording automated equipment is used, manual recording of the temperature readings should be made, just as in the case when only a thermometer is used. These readings should be taken at least once each hour, and more often if it is obvious that a radical change in the room temperature has taken place.

In the areas where a temperature-sensitive product is being processed or tested, or where exacting tolerances are required, automated temperature recording devices are recommended. When this circumstance prevails, a temperature probe should be located in the immediate proximity of the product. It is also advisable to provide an alarm or warning system that will signal temperature variations which exceed either the high or low limit.

5.7.3 Humidity

The requirement for relative humidity within any stipulated range should be based primarily on product needs. Relative humidities above 50 percent may introduce problems, such as rusting of parts and equipment. When abnormally high relative humidities are mandatory, the HEPA filters should have metal separators, and the filter media may deteriorate more rapidly. In addition, trouble may be encountered with the wooden supporting frame through warping and separation of the plywood.

A minimum value of 30% RH should be observed to preclude electrostatic charges on dielectric materials and parts. Such charges can cause serious problems in particle attraction or with explosive components.

5.7.4 Humidity Monitoring

The simplest method for monitoring the relative humidity level is to use a conventional wet and dry bulb thermometer in conjunction with a psychometric chart.

Automated devices may be used to supplement the wet and dry bulb thermometer, but not to replace it. If automated equipment is employed, it should be checked against the thermometer at least once each week, or more often, if significant variations appear in the readings.

5.8 Clean Room Construction Features

The class, type, size, or airflow characteristics will not alter the need for a structure capable of precluding the passage of air into or out of the room except through designated plenums or ducts. Thus, any openings (doors, pass-throughs) must also be capable of air-sealing in a manner which will maintain this essentially airtight condition during all operating periods.

A positive pressure is desirable for all clean rooms. Air leakage into the room would signify a lack of positive pressure. The seepage of air out of the room, if in sufficient volume, could induce undesirable eddy currents and upset the desired airflow pattern within the room. Minor air seepage from the room will not usually be harmful. If the room is not operated on a continuous schedule, however, these openings could permit contaminants to infiltrate the room during nonoperational hours.

5.8.1 Construction Materials

Although normal construction materials are subject to some degree of expansion and contraction when temperature and humidity varies, the average clean room should not undergo such broad variations as to create an air-leakage problem. It is a factor for consideration, however, when stipulating the materials which will be used in the construction of any clean room.

Verification that a room is leak-free should be made when the room is operating within 5 percent of the normal airflow rate, and at the temperature and humidity specified.

Specifying wood construction entails the responsibility to ascertain that reasonable age will not cause drying and shrinkage to the extent that openings and air leakage will occur.

The use of dry-wall construction for a laminar airflow facility has been demonstrated to be satisfactory if the joints are taped, and a nonshedding or nonchalking surface sealing agent is properly applied. The more exotic and costly stainless-steel interior surfaces will preclude the necessity for wall replacement if the facility is to be long-lived, and will also reduce cleaning, maintenance, and repainting costs for wood or dry-wall construction. Thus, selection of the materials for construction of a clean room must be analyzed in the light of anticipated use, and initial cost versus maintenance cost.

The clean room should be located and mounted so as to be free from as much vibration as is feasible, whether induced by adjacent manufacturing activities or by its own air-supply system. High noise levels are capable of having a detrimental effect on a structure. Sound waves will produce vibration and friction between construction members, which in turn will cause particulate generation.

5.8.2 Walls, Ceilings, and Floors

Walls and ceilings (nonfilter areas) should be free from ledges and irregularities, and have the following characteristics:

a. Low-shedding - a sealed, glossy surface is favored

b. Easy to clean - washing or vacuuming

c. Sealed joints - at corners and between panels.

Floors (excepting perforated or grated) should be covered with a material that is able to withstand traffic wear without undue shedding, can be easily cleaned, and is free from cracks or openings into which particulate matter might lodge.

Floors in vertical laminar airflow facilities may be either perforated or grated metal. Stainless steel is preferred because it wears well, is low-shedding, and resists flaking oxide. This type floor should be constructed in sections, so that they may be raised to permit cleaning of the lower plenum.

5.8.3 Plenums and Ducting

Provision for ready access to all plenums for cleaning purposes is very important. Periodic cleaning of all closed areas will greatly increase the productive life of the HEPA filters.

It is desirable that ducting be designed and constructed to provide the capability for dismantling quickly for cleaning. The use of accordian, corrugated or other uneven surfaces should not be used for ducting. Plasticized fabric should not be used for ducting material. The interior surfaces of whatever ducting is employed should be as smooth as possible and as free of ridges or ledges as is economically feasible. The attempt to reduce obstructions, however, must not overshadow a need for each duct to be airtight within each section, and at all joints.

The sharper the bend in a duct, the greater will be the noise and heat developed, and this is especially true when the duct size is at the minimum required. It is recommended that bends have a sufficient radius and that the duct size be adequate to permit free flow of the air.

5.8.4 Airlocks, Doors, and Pass-Throughs

Airlocks are those double-door entryway facilities required for most nonlaminar airflow rooms which are equipped with interacting locks, and have forced ventilation to provide continuous flushing of the air space within the airlock. Airlocks are not required for laminar airflow facilities.

Doors should be self-sealing when closed, should be equipped with exterior mounted pneumatic closers, and be of an adequate size to accommodate the amount of traffic anticipated. If the traffic through the entrance is to be above normal, and cannot be reduced, consideration should be given to a controlled entrance and exit by providing one door for entrance to the room, and another exclusively for exit.

Pass-throughs should be provided if frequent movement of material will occur into and from the room. Their size will depend on the demands of the product to be handled, and only those which are equipped with an interlocking mechanism should be used.

Unless cleaning of product is to be accomplished within the room, no uncleaned material should be permitted in the room. In any event, the external area into which the pass-through leads must also be at least a controlled area.

5.8.5 Anterooms

The extent to which anterooms are provided and equipped depends upon (a) the established and maintained class of air cleanliness of the room, and (b) the planned room occupancy. (The garmenting will have been established by the class of room cleanliness.)

The ultimate would be to provide a HEPA-filtered, contaminant-controlled dressing room, clothing lockers, shoe cleaners, and special washing and warm air, drying facilities. It then becomes necessary to determine how much one may retreat from this sophisticated approach to accommodate the needs of the specific room being considered.

Most nonlaminar airflow facilities require the ultimate approach, as described above. Very few full vertical laminar airflow facilities will require anything approaching the control of the described procedure, but each case must be studied and appraised on its own merits. No generalization is deemed practical.

5.9 Clean Room Furniture and Equipment

The furnishings and equipment for a clean room should be constructed of materials which are subject to minimal chipping, flaking, oxidizing or other deterioration. Paint should be hard and nonflaking or nonchalking. Any furnishing likely to be subjected to abrasion or bumping should be constructed of either stainless steel or a nonfracture-type plastic. Other than clean packaging films, soft or pliable rubbers and plastics should be excluded.

5.9.1 Chairs or Stools

Chairs and stools should not have arm rests, and should be low enough for the workers to rest their feet on the floor. The feet of the chair or stool should be equipped with stainless-steel or heavy chrome-plated glides; coasters should be prohibited. Any movable parts, whether requiring lubrication or not, should be fully and completely enclosed to preclude the releasing of generated particles, oil droplets, or chips.

5.9.2 Benches and Work Surfaces

For general applications, a stainless-steel or laminated plastic work surface is desirable. Legs of benches should be constructed of materials which will resist abrading, chipping, flaking or oxidizing, and in addition should be designed to provide a solid nonvibrating work surface. The bench height from the floor should be specifically stipulated at a point which will permit the seated workers to function without undue strain or fatigue, with both feet firmly planted on the floor. Benches should not have foot rests nor bracing, which may be used for this purpose. A 1/4 to 1/2-inch bevel along the front edge of the bench will be beneficial in that it will reduce the opportunity of chipping which may occur if square edges are present.

The benches should be specified as without drawers, but they may have flat metal or laminated plastic trays which pull out from under the work surface.

5.9.3 Equipment

Very often a specific piece of equipment can be modified so as to place the particulate generating portion of the machine on the outside of the clean room, with just the controls and gages being mounted within the clean room proper. The probability of a slight increase in cost will be more than offset by the reduction in heat and contaminants generated within the room. Easier maintenance is also a factor.

If modification of the equipment is not feasible, then all motors, belts, chain drives, and friction drives must be enclosed to preclude the particulate matter generated from being introduced into the room.

Bulky test, calibrating, and aligning equipment used in the rooms should not be situated facing either the inlet or exhaust filter bank, but rather should be turned 90 degrees to permit the airstream to wash the product when using a horizontal airflow room. The position of the equipment is less critical in a vertical facility. The presence of this type of equipment in a nonlaminar airflow room usually results in the room being "out-of-control" most of the time, due to its low clean-down capability.

5.10 Clean Room Garments

The primary purpose for garmenting clean room workers is to contain as much of the particulate matter brought into the area on the person and attire of the worker as is possible. Secondarily, an adequate garment will also contain the particulate matter generated from the person and attire during the period that the garment is worn. This secondary condition is evidence that once a garment is worn, it will have particles of contamination on the inside, and unless the fabric weave is sufficiently impenetrable, it too will emit particles.

5.10.1 Fabrics

Selection of the fabrics used in the garments, whether purchased or rented, should be specified in detail, with the burden of proof of the contents of the fabrics resting upon the supplier of the fabrics. Not all fabricators of clean room garments maintain a laboratory for the purpose of ascertaining and certifying that they are really using the type of material specified. Cotton and linen outer garments should be excluded from a tightly controlled clean facility because of their high linting characteristics and low abrasive resistance.

Following is a general description of readily available synthetic fabrics, and some specific characteristics of each:

Nylon - 100-percent multiplex continuous filament, taffeta weave, having superior abrasive resistance, high absorbency, minimum linting, and outstanding wearing qualities.

Nylon - 100-percent continuous filament yarn, taffeta weave, is long wearing, and has very good abrasive resistance.

Nylon - 100-percent double-knitted monofilament yarn is highly porous, very high in abrasive resistance, and has superior absorbent qualities. Used for wiping cloths.

Nylon - 100-percent monofilament, lightweight tricot knit makes an excellent glove fabric. It is inexpensive, high in porosity, minimal adsorbency, and is extremely resistant to linting.

Nylon - 100-percent monofilament base coated with a thin film of polyvinyl chloride is completely nonporous, has no adsorbancy, and was specifically developed for gloves to prevent transfer of skin contamination. Cannot be dry cleaned, and is sensitive to acetone, perchloroethylene, and similar solvents.

Nylon - 100-percent continuous filament, very tightly woven taffeta, fine denier fabric, calendered, is nonporous, nonadsorbent, with high abrasive resistance. Designed to be LOX-compatible.

Nylon - 100-percent stretch tricot, specifically designed for gloves. It is sensitive to abrasion, and moderately adsorbent.

Dacron Polyester - 100-percent polyester continuous filament yarn, plain taffeta weave, is an opaque tightly woven fabric with long wearing and acid-resistance characteristics.

Dacron Polyester - 100-percent polyester continuous filament yarn in a herringbone twill to provide body and weight. It is opaque, very long wearing, very tough and sturdy, and acid resistant.

In addition to the above synthetic fabrics, there are a large number of combinations of dacron and viscose rayon types, which are somewhat cheaper per yard than the straight synthetic. It should be remembered that when viscose rayon is added to other yarns to produce a fabric, some of the strength is sacrificed when the fabric encounters moisture. The addition of viscose rayon will reduce the generation of static electricity, with the degree of reduction related to the percentage of rayon in the fabric.

5.10.2 Garment Construction

All garments should be sewed with thread of 100-percent polyester continuous filament, stranded, 200 denier minimum, and for appearance, should be the same color as the garment.

All seams must be CLOSED, DOUBLE-STITCHED, and FREE OF LOOSE THREADS.

Garments should not have pockets. The garment should be equipped with adjustable collars and cuffs, which have stainless-steel snap fasteners.

5.10.3 Soiling and Laundering

How frequently should garments be cleaned or laundered? Arriving at a good answer requires consideration of the following conditions, all of which may contribute to the contamination of the garment:

a. Rate of personal emission varies from one individual to another.

b. Amount of physical movement by the wearer may vary among individuals having the same work assignment.

c. Heat and cold environments will create particulate generation rates from high to low from different persons.

d. A high incidence of particulate generation will occur from tweeds, bulky sweaters, starched cotton, and linen fabrics.

e. Contamination which is acquired from the operation or tools used on the job.

The monitoring techniques for laundered garments in ASTM F-51-65T are recommended for use in ascertaining the amount of contaminants contained in garments worn for various periods, by different individuals. A satisfactory change cycle can be developed from an analysis of this data.

Laundering must be accomplished in an airborne contamination controlled facility, Class 100,000 or better, per FED-STD 209a. Provisions should be made for the contracting organization to make periodic inspections of the laundry facility, to be sure that all necessary steps are taken to maintain the required cleanliness levels.

5.11 Monitoring

Techniques for monitoring airborne contaminants are categorized by the methods applicable to the types or classes of contaminants. In terms of broad considerations, the contaminants encountered in atmospheric and air-supply conditions are grouped according to their physical characteristics:

a. Gases -- Organic and inorganic which includes vapors from substances that are normally solid or liquid.

b. Aerosols -- Solid and liquid particulate matter suspended or entrained in the airstream.

c. Combinations or Mixtures of Gases and Aerosols -- May be heterogeneous mixtures or may be solids and vapor phases of the same substance.

Monitoring of airborne contaminants involves sample collections and the tests for identifying and measuring the concentrations. The principal objective in air monitoring is to evaluate the composition of the air by qualitative and quantitative analysis for any constituents which may be potential contaminants in a particular area or location. Some constituents may be considered contaminants in extremely low concentrations, whereas others have little or no contaminating effect. Based on the air-monitoring evaluation as related to the requirements in a particular location, the need for control measures can be established or the effectiveness of existing controls can be measured. Some areas where monitoring is commonly employed are:

a. To determine the contamination resulting from a process or operation to evaluate the process.

b. To evaluate the performance of control equipment employed in a process or operation.

c. To evaluate the environment with reference to hygienic and health standards for personnel in an area.

d. To correlate environmental conditions with medical findings in order to establish threshold limit values for specific contaminants.

e. To ascertain whether explosive concentrations of a contaminant exist in an area.

For the purpose of determining methods for sampling and analyzing, most contaminants may be grouped according to their solubility. Gases and vapors may be grouped as follows:

a. Water soluble or miscible and can therefore be collected in water.

b. Not water soluble but are soluble or highly reactive to other agents and can be absorbed or will react readily with a particular solvent or agent.

c. Not water soluble and which react slowly with absorbing agents, therefore requiring longer treatment for collection.

Aerosol dusts may be grouped as follows:

a. Relatively insoluble mineral dusts, e.g., silica, granite, asbestos, and insoluble metal oxides.

b. Soluble mineral dusts, e.g., limestone and dolomite which are soluble in water or weak acids.

c. Organic dusts which may or may not be affected by water, e.g., flour, soap, leather, wood, plastics, trinitrotoluene (TNT) and insecticides. These dusts are usually explosive in high concentrations.

Aerosol fumes, smokes, and liquid mists are usually considered in the same category as dusts; however, for air-sampling purposes, it is necessary to classify them according to the type of analysis required.

5.11.1 Air Sampling and Collection Methods

The two basic types of air sampling are:

a. Grab Sample -- The collection of a sample at a given time in or on a collecting device. For gases and vapors, a given volume of air is collected in a container for analytical examination. For particulate matter, the particulate matter from a given volume of air is separated on a collecting device for analytical examination.

   This type sampling, also called "SPOT" and "SNAP," is limited in that the analytical measurement of contaminants in the sample represent the air at the location and the time the sample is taken, and is not necessarily indicative of air contaminants at the same spot at any other time. Periodic sampling over a period of time may provide an indication of the normal level of contamination, which may or may not be adequate.

b. Continuous Sample -- The movement of a volume of air at a constant rate through a device capable of measuring the contaminant concentration level at any given moment or continually during operation.

   This type sampling may be adapted to direct readout and automated recording which can provide a constant and continuing record of the concentration level of contaminants. This type requires more complex and sophisticated equipment and may be limited to a specific contaminant, dependent on the type.

The sampling equipment, devices, and procedure used will depend on the analytical techniques and instrumentation required for the qualitative and quantitative analysis of the contaminants under investigation. The sensitivity and accuracy of the analysis method depend upon the efficiency of the collection method. Factors influencing the efficiency of sample collection that should be considered in the selection of a method include:

a. Forn of the contaminant under investigation, e.g., solid, liquid, or gas. The presence of the contaminant in more than one form may necessitate parallel or series sampling with different equipment and procedures.

b. Particle sizes involved (molecular and larger)

c. Density

d. Solubility

e. Vapor pressure

f. Dew or sublimation point

g. Freezing point

h. Chemical reactivity

i. Radiant energy absorption

j. Thermal conductivity

k. Ionization characteristics

l. Presence of other substances which could interfere with the collection or retention of a specific contaminant.

Sample collection methods may be grouped by their principle of operation for the basic types of contaminants.

a. Methods for gases and vapors are:

(1) air displacement

(2) condensation

(3) gas washing

(4) adsorption.

b. Methods for dusts are:

(1) settling collection

(2) collection by filtration

(3) inertial collectors

(4) electrostatic precipitators

(5) thermal precipitators

(6) Particle counting (light scattering or light absorption).

c. Methods for fumes, smoke, and liquid mists depend on the type of analysis performed such as chemical analysis of liquids and fumes, and density of smoke.

Air sampling, to be of significant value, must be truly representative of the air in a particular area or point of interest. Concentration levels of airborne contaminants are affected by the air currents and cross drafts. Aerosols are further affected by gravity and electrostatic forces. The selection of sites for sampling should give consideration to these factors as well as other influential conditions such as movement of personnel and equipment and location of other sources of contaminants with relation to the direction and velocity of the air. These factors are of vital importance whether the sampling is of the outside atmosphere or in a confined space such as a clean room or clean bench. The procedures employed in obtaining the sample and handling the sampling equipment should preclude introducing extraneous contaminants in the sample.

5.11.2 Analytical Methods and Instrumentation

Analysis of the air sample consists of identifying and measuring the contaminants. Selection of analytical methods must be compatible with the sample collection technique employed and is dependent on the contaminants of interest and the analytical information required. Items for consideration include:

a. Type of contaminants to be analyzed. Gases and vapors or aerosols. Other factors include those listed for collection methods in the previous paragraph.

b. Is identification of the contaminant required for a quantitative measurement? May require a specific-type method.

c. Are particular contaminants identified requiring quantitative measurement only? Nonspecific-type methods may be used.

d. Are levels or ranges of concentrations of particular contaminants known within which measurements shall be made? Establishes sensitivity required.

e. Sampling type and collection method employed.

f. Are direct reading devices and instrumentation required for immediate results of analysis?

g. Are automated recording devices required for analysis of results.

The sampling, analysis methods, and instrumentation must be tailored to the type facility or operation, the information requirements, and the type of contaminants. The selection of equipment must therefore be determined on an individual basis.

The analysis of gases and vapors is the measurement of the chemical composition of a gas. The chemical analysis methods are fundamentally based on the interaction between matter and energy. Observation of the results of the interaction between a substance and some external energy source provides means of identifying and measuring the composition of a particular substance. Variations in the interactions by the types of energy sources that may be used determine the analytical technique that may be employed. Table 5-13 provides a list of some of the commonly used gas and vapor techniques applicable to each of the fundamental types of energy sources. However, many of these techniques are also used in the chemical analysis of solids and liquids.

TABLE 5-13

Gas and Vapor Chemical Analysis Techniques

Techniques	Type Interaction	Definition	Energy Used
Ultraviolet spectrophotometry	Transmission and reflection	Measurement of the quantity and quality of electromagnetic radiation emitted, reflected, transmitted, or diffracted by the sample	Electromagnetic radiation
Light scattering			
Infrared spectrophotometry			
Microwave spectroscopy			
Orsat analyzer	Consumption of sample or reactant	Measurement of results in terms of amount of sample or reactant consumed, product formed, thermal energy liberated, or equilibrium attained	Reaction with other chemicals
Automatic titrators			
Impregnated tape	Measurement of reaction products		
Photometry			
Colorimetry			
Gas chromatography			
Combustion	Thermal energy liberation		
Other thermic reaction			
Mass spectroscopy Nier type Omegatron Time of flight	Ion separation	Measurement of the current, voltage, or flux changes produced in energized electrical and magnetic circuits containing the sample	Electrical and magnetic fields
Gaseous conduction	Electrical properties		
Paramagnetism	Magnetic properties		
Nuclear magnetic resonance			
Conductivity	Thermal	Measurement of results of applying thermal or mechanical energy to a system in terms of energy transmission, work done, or physical state	Thermal or mechanical energy
Dew point			
Sound velocity	Mechanical		

The analysis of aerosols involves the identification of the physical properties or chemical composition of the particulate matter and a quantitative measure.

Identification of particles can usually be accomplished optically by incident or transmitted light with a microscope. The origin and composition can be deduced from the size, shape, color, and texture unique to particular types of matter. Other methods of identification include the principles of chemical analysis as defined in the preceding paragraph for gases.

Quantitative measurement of particulate matter is normally accomplished by counting and sizing the particles when the concentration levels are low or by analytical weighing for high concentrations. The techniques consist principally of light scattering, volume displacement, microscopy, and weight analysis. The microscopic method is the only one of these that can provide a qualitative identification by observing the difference in appearance of the individual particles. However, the microscopic method is not recommended as a quantitative analysis technique for particulate matter below 5.0-micron size. Table 5-14 lists the commonly used methods for monitoring aerosols. A wide variety of instruments is available for each of the analysis methods, and should be selected in accordance with the individual monitoring requirements for the particular application.

Selected methods for analysis of a group of airborne contaminants commonly encountered are listed below. These methods are presented in a uniform format in Public Health Service Publication No. 999-AP-11* which includes details on the analytical methods and procedure.

Contaminant	Method
Sulfur dioxide	West and Gaeke Hydrogen peroxide
Nitrogen dioxide and nitric oxide	Saltzman
Oxidents (including ozone)	Neutral buffered potassium iodide Alkaline potassium iodide
Aliphatic aldehydes	3-methyl-2-benzothiazolone hydrazone hydrochloride (MBTH)
Acorlein	4-hexylresorcinol
Formaldehyde	Chromotropic acid
Sulfate in particulates	Turbidimetric barium sulfate
Nitrate in particulates	2,4 xylenol

*Selected Methods for the Measurement of Air Pollutants, No. 999-AP-11, U.S. Department H.E.W., Public Health Service, Division of Air Pollution, Washington, D.C., May 1965.

TABLE 5-14

Principal Methods for Monitoring Aerosols

Method	Principle of Operation	Type Sample	Comments
Light scattering	Light scattered by particles passing through a high intensity light beam is detected and converted to electrical pulses by a photomultiplier tube.	-------	This method produces the least physical effect on the particles themselves and has high sensitivity. Particle sizes range from 0.3 to 30 microns. No qualitative data can be obtained.
Particle counters	Pulses corresponding to individual particles are electronically separated, sized, and counted.	Continuous	Excellent for analytical work where size and concentration versus instantaneous event is desired.
Level indicators	Pulses from photomultiplier are integrated to indicate an average level.	Continuous	Less expensive than particle counters. Dust level fluctuation versus time easily obtained. Good for continuous monitoring of medium and high concentrations.
Volume displacement	Particles suspended in an electrolyte are drawn through a small aperture. An individual particle displaces its own volume of fluid producing a resultant electrical pulse proportional to the particle size.	Grab	Gives true particle volume measurement. Some types of particles will be dissolved or altered when suspended in solution. Unsuitable for continuous monitoring. No qualitative data can be obtained.
Microscopic	Collected particles are counted and analyzed by microscopic methods.	-------	This method provides the best qualitative information for source identification. Requires a trained operator.
Settling collection	Particles are allowed to settle out on some collecting and counting surface.	Grab (cumulative)	Sees particles settle out, similar to a product. Requires long sample time with time lag in obtaining results.
Filtration collection	Particles are strained from air sample by a membrane filter.	Grab (cumulative)	Provides a quick sample for spot checks. Particulate matter captured on a filter is difficult to resolve in the smaller size ranges.
Impaction collection	Air is forced through a small aperture at near sonic velocity. By placing a collecting surface in the air path the particles are separated out by inertial forces and caused to adhere on the collecting surface.	Grab (cumulative)	Provides quick sample. Method is most sensitive to one particular size range depending on orifice. Multiple stages with different size orifice used to collect a wide range of particle sizes. Matter may be altered by forces involved.
Electrostatic precipitation collection	Particles charged in a high potential field are collected on metal surface of opposite polarity.	Grab (cumulative)	Requires short sample time. Particles must be collected on metal surface. Requires high voltage.
Thermal precipitation	Particles passed between surfaces with a temperature differential and collected on the cooler surface for counting.	Grab (cumulative)	Very low collection rate and low efficiency for large particles.
Weight analysis	Particles collected by any method and are weighed analytically.	Grab	Provides no qualitative data. Insensitive to low concentrations. Suitable for gross contamination measuring only.

Additional information on specific types of instruments and equipment used for air sampling and analysis is presented in the American Conference of Governmental Industrial Hygienists Manual on Air Sampling Instruments.* Continuing activity in the development of instruments and techniques for the analytical measurement of airborne contaminants requires careful consideration of the latest developments in the selection of such equipment.

Standards and specifications applicable to the monitoring of airborne contaminants include:

a. FED. STD. No. 209a, Clean Room and Work Station Requirements, Controlled Environment, August 10, 1966. Provides requirements for tests and monitoring of clean rooms and clean work stations.

b. MIL-F-51068A, Filter, Particulate, High-Efficiency, Fire Resistant, April 23, 1964. Provides inspection and test procedures and acceptance criteria for high efficiency particulate (HEPA) filter units.

c. ASTM F25-66T, Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust-Controlled Areas Designed for Electronic and Similar Applications, September 21, 1966. Covers a procedure for counting and sizing airborne particulate matter in the size range of 5.0 microns and larger. Includes a description of apparatus required for sample collection, sizing and counting operations employing the microscopic analysis method.

d. ASTM F50-65T, Continuous Counting and Sizing of Airborne Particles in Dust-Controlled Areas by the Light Scattering Principle (for Electronic and Similar Applications), February 17, 1965. A method of determining the concentration and size distribution of airborne particulate matter in the size range of 0.5 to 5.0 microns. Utilizes the light-scattering principle to detect and size particles in the airstream. Includes a description of apparatus for continuous sampling of the airstream and instrumentation for counting and sizing particles on a continuous basis.

e. ASTM F51-65T, Sizing and Counting Particulate Contaminants in and on Clean Room Garments, July 22, 1965. A method for determining detachable particulate contaminants, 5 microns and larger, in and on the fabric of clean room garments. Utilizes the microscopic analysis method as in ASTM F25.

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*Air Sampling Instruments, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (1962).

5.11.3 Filter and Filter Bank Testing

A clean room or enclosure is fundamentally an area in which airborne contaminants can be controlled to some predetermined level. The capacity of an enclosure to function and be maintained at some required level of air cleanliness is dependent on two basic factors:

a. All the air introduced into the enclosure is cleaned by passing it through a high efficiency filtration system.

b. The clean air must be distributed in such a manner that recontamination of the air in the enclosure does not exceed the prescribed air-cleanliness level.

Verifying the efficiency of the filtration system involves checking and testing for air leaks and monitoring for contaminant level.

Verifying that the air is maintained at some prescribed cleanliness level involves a variety of tests, and monitoring techniques, dependent on the type and configuration of the facility.

Clean air enclosures use high-efficiency filter systems employing the HEPA filter, and utilize either the nonlaminar or laminar airflow principle.

The HEPA filter is capable of providing a minimum efficiency of 99.97 percent for 0.3-micron diameter particles provided there are no leaks in the filter or filter bank. The sources of filter and filter bank leakage are listed below and illustrated in Figure 5-19, showing a cross section of a filter installation:

a. Leaks in the filter media.

b. Leaks in the bonding of the filter media to the filter frame.

c. Leaks in the gasket between the filter frame and the filter bank support frames.

d. Leaks in the filter bank support frame.

e. Leaks at the junction of the filter bank support frame and the walls of the enclosure.

The method for locating leaks in filters and filter banks consists of introducing a concentration of homogeneous DOP (dioctylphthalate) smoke under pressure on the upstream side of the filter or filter bank to be tested. The downstream side of the filter or filter bank is scanned over the entire face area with the probe of an aerosol photometer. A leak is indicated by any steady reading on the photometer meter. Slight deflections of short duration on the meter may be caused by material flaking from inside the sampling tube or from the filter face by accidental contact with the probe.

NOTES: 1. LEAKS IN FILTER MEDIA. 2. LEAKS IN BOND BETWEEN MEDIA AND FRAME. 3. LEAK IN GASKET BETWEEN FILTER FRAME AND SUPPORT FRAME. 4. LEAK IN SUPPORT FRAME. 5. LEAK BETWEEN SUPPORT FRAME AND WALL.

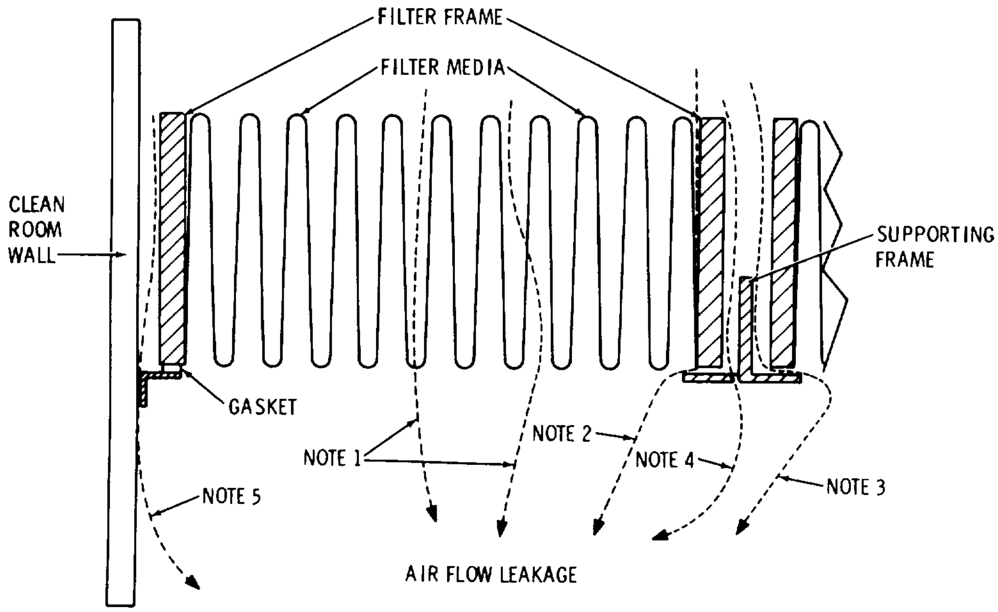


Figure 5-19. Typical sources of air leaks in a filter bank installation

The equipment required for the DOP smoke test for an unmounted filter is as follows:

a. A filter unit test assembly consisting of a plenum box with an attached blower and a clamping assembly and frame for clamping the filter to the plenum box.

   Figure 5-20 illustrates the basic parts of such a test assembly. The blower shall be capable of producing an airflow velocity of 100 ± 20 ft/min. through the test filter. The length and width of the plenum box and clamp frame shall be the same size as the test filter. The depth of the plenum box for a 24 x 24-inch filter should be approximately 10 inches. For other size filters, the depth should be proportional to the filter size to provide uniform distribution of air over the filter area.

   The depth of the clamp frame should be sufficient to provide a uniform airflow an adequate distance from the filter face for proper testing.

b. A smoke generator using high-velocity atomizing nozzle submerged in DOP liquid. Figure 5-21 is a simplified diagram of a typical DOP smoke generator.

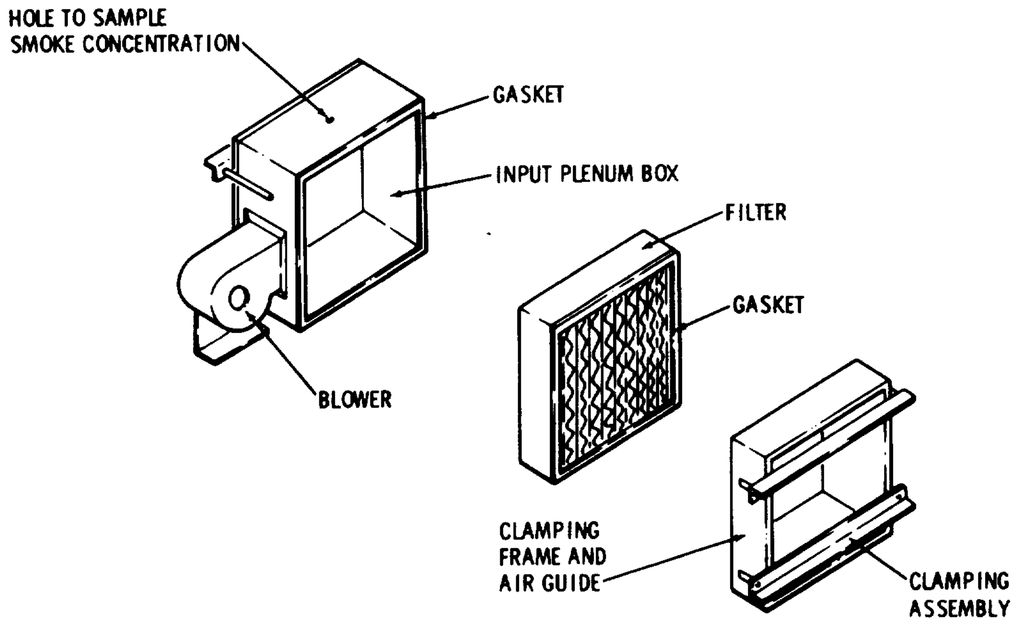


Figure 5-20. Filter unit test assembly

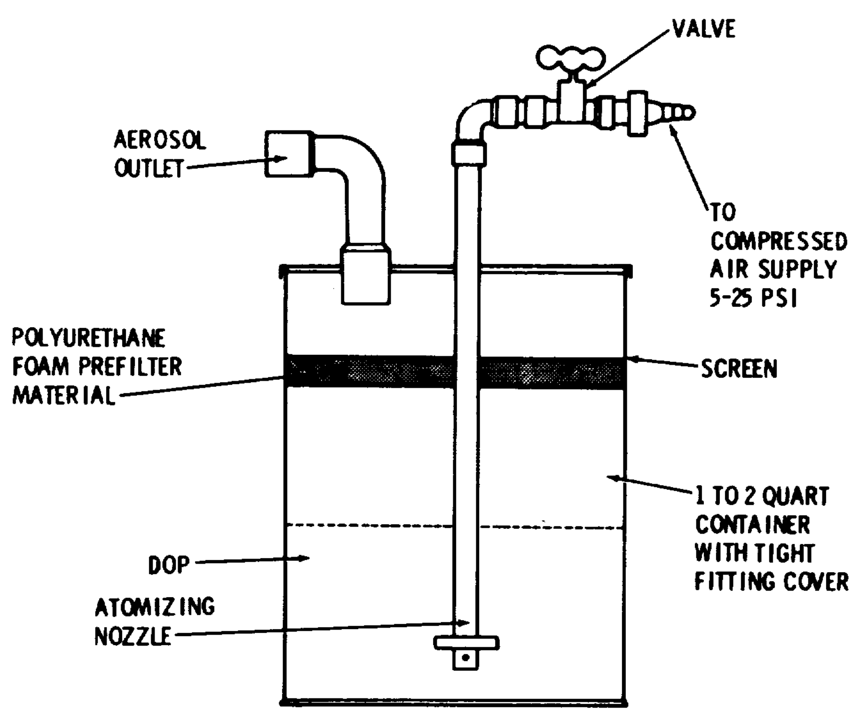
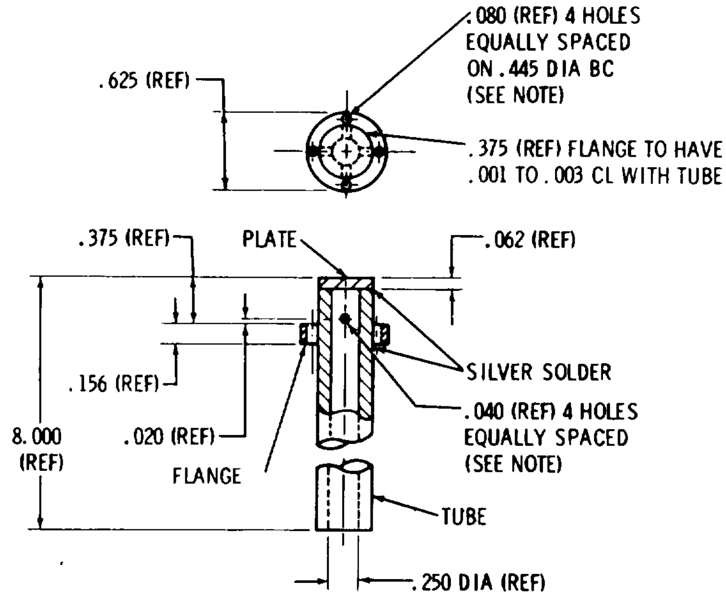


Figure 5-21. Typical DOP smoke generator

c. The atomizing nozzle for the smoke generator may be made with 1, 2, 3, or 4 jets (holes) to vary the output of smoke at a given air pressure. For stability, the pressure on the nozzle should be greater than 15 psi. Figure 5-22 provides details for fabrication of a nozzle.



NOTE: THE NOZZLE MAY BE CONSTRUCTED WITH 1, 2, 3, OR 4 HOLES (JETS) TO VARY THE OUTPUT CONCENTRATION OF THE NOZZLE.

Figure 5-22. Atomizing nozzle

The selection of the number of jets per nozzle or, in the case of testing a filter bank, the number of generators needed will be determined by the volume of air to which the smoke is added. The following table is a guide in selecting the number of jets per nozzle and the number of nozzles required for a given volume of air.

Volume of Air (cfm) (see note)	Number of Nozzles	Number of Jets per Nozzle
400 to 500	1	1
501 to 800	1	2
801 to 1200	1	4
1201 to 2000	2	4
More than 2000	As required	As required

Note: The volume of air denotes the amount of air passed through the filter system under test, e.g., a single 2 x 2-ft filter with air passing through a 100 ft/min. (filter face velocity) is equivalent to an air volume of 400 cfm.

d. A compressed air supply capable of producing pressures of 5 to 25 lb/in.^{2} (psi), to supply air to the smoke generator.

e. An aerosol photometer capable of detecting a 0.01-percent leak of the smoke concentration introduced on the upstream side of the filter.

A procedure for testing a single filter prior to installation is as follows:

a. Clamp the test filter in the filter unit test assembly.

b. Place the smoke generator to introduce smoke into the plenum blower.

c. Set up the aerosol photometer, and calibrate per manufacturer's instructions.

d. Turn on the blower and the smoke generator and adjust the smoke until a reading of 4.0 (on logarithmic scale) is obtained in the plenum box when measured by the photometer.

e. Holding the photometer probe 1 to 2 inches from the filter face, scan the entire downstream surface of the test filter.

f. Determine any leaks in the media or in the bonding between the media and the frame.

A procedure for testing a filter bank assembly by introducing smoke into the air-supply plenum is described below. Multiple smoke generators or a high-capacity generator will be required to produce sufficient smoke for this test:

a. Place the smoke generator(s) at the most appropriate location to introduce smoke into the air-supply plenum of the facility. This location may be:

   (1) into the air duct(s) immediately upstream of the final filter for nonlaminar airflow facilities

   (2) into the air-supply plenum for laminar airflow rooms

   (3) into the air-supply intake of a laminar airflow work station

   (4) into the air intake of modular air systems. This necessitates testing single modules individually.

b. Set up the aerosol photometer, and calibrate per manufacturer's instructions.

c. Turn on the air-supply system blowers and the smoke generator(s). Adjust the smoke until a reading of 4.0 (on logarithmic scale) is obtained in the air-supply plenum when measured by the photometer.

d. Holding the photometer probe 1 to 2 inches from the face of the filter bank, scan the entire downstream surface of the filter bank under test.

e. Determine any leaks in the filters, between filters and filter bank supports, in the support frames, and between support frame and sides or walls.

Two alternate methods of filter bank leak testing are listed here for information. It is not intended that either of these methods replace the complete testing of individual filters. Since both of these methods are visual, the accuracy of the test results depends on the observations and interpretations of the operator.

a. The first method requires a reduced air supply in the air-supply plenum of approximately 50 to 60 percent of normal operating capacity. This may be accomplished only if the facility is equipped with variable speed blowers or multiple blower units. DOP smoke is introduced into the air-supply plenum and the room lights are turned off. A restricted beam, high-intensity light source is directed parallel to and near the filter bank face. Smoke plumes resulting from leaks are usually detectable when viewed looking toward the light source at a 30 to 45-degree angle from the light beam and with a dark background from the angle of view.

b. The second method, developed by the Atomic Energy Commission, involves introducing an aerosol fluorescent dye into the air-supply plenum. A piece of porous cloth is placed over the downstream side of the filter bank and the blowers are activated for a short time. The cloth is then scanned with an ultraviolet light source for the location and relative size of leaks. This method can be varied by deleting the cloth and merely scanning the downstream side of the filter bank, but the results may be somewhat less perceptible.

To repair leaks in filters and filter banks, a patch of silicone RTV compound may be used. Extreme care is required in making patch repairs of this kind to assure that the hole or crack is completely sealed. An inadequate seal will result in dispersing the air to the edges of the patch, and diffusion of the unfiltered air into clean air makes it more difficult to detect the leak. Examples of leaks that may be effectively sealed in this manner are:

a. Holes in filter media at exterior fold

b. Holes between the filter media and frame

c. Cracks or holes in and around the support framework

d. Holes in the filter media which are inaccessible between the folds are normally cause for rejecting the filter unit. However, in some cases this type leak can be repaired by forming a patch over the entire length of the fold, sealing the RTV patch to the media on both sides of the divider and to the divider, and at both ends to the frame.

Leaks in the gaskets between the filter unit frame and the support frame should be corrected by increasing the pressure on the gasket, smoothing or cleaning the mating surfaces, or replacing the gasket.

All repaired areas should be retested to verify the effectiveness of the seal.

5.11.4 Nonlaminar Airflow Facilities

The limited clean-down capability of a nonlaminar airflow room establishes the need for good monitoring practices. A method of continuously monitoring or frequent air sampling is required to assure that the room is maintained within the required cleanliness level.

The methods employed for monitoring and verifying that a nonlaminar airflow room is within the specified cleanliness level will depend on a number of factors unique to the particular room. Some of the factors to be considered are:

a. Normal airflow patterns within the room

b. Personnel movements within the room that add turbulence which disturbs the normal airflow patterns

c. Personnel and equipment moving into and out of the room adding to the airflow disturbance and contributing additional contaminants

d. Location of operations and equipment which generate contaminants

e. Location of critical operations requiring the cleanest environment

f. Selection of multiple points for air sampling that will provide the best indication of the cleanliness level for the room and at critical operating locations.

The procedure to decontaminate a nonlaminar airflow room is quite extensive. Decontamination of a room is required for initial operation or whenever a room exceeds the cleanliness level required. The following is a list of inspections, checks, tests, and operations that should be performed in bringing a room within a required level:

a. For a room that is in operation, all operations in the room should cease, all critical material should be protected from contamination by covers, package or container, and all operating personnel should be removed from the room.

b. Check all equipment and material in the room, removing everything that is not essential to the processes and operations performed in the room.

c. Inspect all equipment and materials essential to the processes and operations performed in the room. Replace or enclose items which are of high shedding material or generate contaminants when in use.

d. With the clean air-supply system in operation, measure the airborne particle count of the filtered air directly in front of the entrance grille(s). If the particle count level is in excess of the required limits, corrective action should include:

(1) Leak-testing the HEPA filters; repair or replace as required.

(2) The air-supply ducts should be tested for leaks, inspected to ensure clean nonshedding interior surfaces and rigid vibration free mounting. Repair, clean or replace as required.

e. Measure the pressure differential between the inside of the room and adjacent areas. The blower capacity should be adequate to maintain an overpressure in the room at all times. If an adequate overpressure does not exist, corrective measures include:

(1) Increase the blower capacity and filter capacity, as required.

(2) Seal any leaks in the air-supply ductwork.

(3) Seal any leaks in the enclosure walls, ceiling, and floor, structural joints and seams. These should be corrected mechanically, except for minor leaks which may be sealed with RTV compound.

(4) Seal and adjust airlock devices of all entryways to eliminate pressure losses.

f. Clean the entire interior of the room including all its contents in the following sequence:

(1) Vacuum with an externally located vacuum system, or special design cleaner with HEPA filtered exhaust.

(2) Prewash with low residue liquid using synthetic sponges. This step may be omitted if the interior surfaces can be adequately cleaned by the "final wash."

(3) Final wash with low residue liquid (i.e., isopropyl alcohol) and clean lint-free cloths.

(4) Vacuum as in (1) above after surfaces are thoroughly dry.

g. Measure the airborne particle count at selected critical points. Measurements or monitoring may have to continue for an extended period of time to assure that the room is within the level required.

h. Repeat all or portions of the above procedures (specifically the cleaning operations) as required until the room is at the required level of cleanliness.

The air-supply system must be in continuous operation during the decontamination procedure and must be continuously operated to maintain a cleanliness level.

All personnel entering the room must be properly garbed and air-showered prior to entry, and all equipment and material must be wiped and cleaned prior to being brought into the room. This is a requirement during decontamination as well as during all subsequent operations.

Other nonlaminar airflow enclosures (i.e., benches, hoods, etc.) may be decontaminated utilizing the same procedures outlined for the room as they may apply to the particular enclosure. Anytime the filtered air-supply system is adjusted or worked on, a cleaning procedure may be required.

5.11.5 Laminar Airflow Facilities

The verification and monitoring of laminar airflow facilities may be categorized as follows:

a. Initial acceptance test with the clean air-supply system in operation and the enclosure devoid of all equipment except for built-in features.

b. Periodic verification of all parameters of the facility in normal operation, with all normal work activities in progress and all equipment and materials in place.

c. Periodic or continuous monitoring of selected parameters of the facility in normal operation.

A properly designed and operating laminar airflow facility provides a volume of clean air traveling through the enclosure which entrains and exhausts airborne contaminants. The airflow will not remove contaminants deposited on surfaces. Contaminants that are released into the airstream will be detected only downstream from the point of release.

The fundamental conditions which must exist for the proper operation of a laminar airflow clean facility are:

a. The HEPA filters and filter bank must be leak-free.

b. The air velocity across the entire face of the filter bank and from the filter bank to the exhaust area should be essentially uniform.

c. The direction of airflow from the filter bank to the exhaust area should be essentially uniform and parallel to a plane perpendicular to the filter bank face.

A procedure to verify proper operation of a laminar airflow clean room should include:

a. Leak-testing the filter bank in accordance with methods described in Paragraph 5.11.3, to assure a leak-free filter bank assembly.

b. Measuring the air velocity 12 to 24 inches from the face of the filter bank. A measurement should be made for each 16 to 36 square foot area of filter bank. All measurements should be within 10 percent of the specified face velocity. If out-of-tolerance conditions are detected, additional points of measurement may be required to locate the cause. Out-of-tolerance conditions may result from:

   (1) clogged or inoperative filters or incorrect capacity filters

   (2) nonuniform air distribution in the air-supply plenum

   (3) incorrect capacity of air blowers.

   With the face velocity within specified limits throughout the filter bank area, measure the velocity midway between the filter bank and the exhaust area and also near the exhaust area. Points of measurement should be made in the same grid pattern that was used at the filter bank face. The air velocity in these areas should be essentially within the same limits as the face velocity, except when a large object is upstream or near the point of measurement causing a major deflection of the airstream. Other significant variations in velocity may be the result of:

   (1) major leaks or openings in the walls of the enclosure

   (2) obstructions in the exhaust grille or plenum which impede airflow

   (3) improper adjustment of exhaust plenum baffles.

c. Checking the direction of airflow and dispersion pattern of the airstream by visual observation (or light-scattering-type particle counter) of smoke generated at points 12 to 24 inches from the face of the filter bank. A slight dispersion is normal, but the dispersion patterns should be essentially parallel to the initial direction of flow. Any significant nonuniformity or drift of the dispersion pattern may be caused by:

   (1) nonuniformity in air velocity (see "b" above)

   (2) objects in the room causing turbulence or major shift in the airflow direction

(3) improper adjustment of exhaust plenum baffles.

This test may be used to good advantage in the placement of equipment and selection of operational locations within the room to minimize potential contaminant migration.

The number of points for this check may be as determined for the air-velocity measurements or, as required, in determining dispersion patterns around equipment and work locations.

d. Measuring the pressure differential between the room and adjacent areas. The positive pressure differential should be 0.05-inch water gage minimum with all entryways closed. With entryways open, the blower capacity should be adequate to maintain an outward flow of air. Inability to maintain minimum pressure may be due to inadequate blower capacity or leaks in the enclosure walls, air ducts, and plenums. Pressure measurements may be made with a manometer or magnehelic pressure gage.

e. Measuring the temperature and humidity at representative locations within the room. Readings should be within the limits specified. The air-tempering equipment must be capable of maintaining the air within the specified limits during normal operational activity within the room.

f. Measuring the air cleanliness within a room may be performed with a light-scattering-type particle counter. The requirements for these measurements are largely dependent on the type of room and the operations being performed in the room.

(1) Vertical flow room -- When no operational activity is being performed in this type of room, particle counts may be made at normal working height of critical operations and at various locations within the room. The particle count should not exceed that obtained at the face of the filter bank. Any significant measurement indicates leaks in the filter bank, shedding of the filter media or other material released from protective screens, diffusers, light fixtures, sprinkler heads, etc.

When normal operational activities are in progress in the room, particle counts should be made over and around each operation. This provides a measure of the particulates being generated by the operation and the extent of dispersion around the activity.

(2) Horizontal flow room -- Measure the particle count at normal working height and 4 to 6 inches upstream at points along the first row of operating positions which are parallel to the filter bank. The particle count at these points should not exceed the measurements

obtained at the face of the filters. These measurements should not be affected by operational activities. They establish the air-cleanliness class for the first row of operating locations. Any significant measurement indicates leaks in the filter bank or shedding of the filter media or materials downstream from the filter face.

When all operational activities are in progress, measure the particle count, in the same manner described above, at points along each of the subsequent rows of operating positions downstream from the first row. The particle counts along each row will reflect the particulates generated by upstream operations and migrating to that location. These measurements establish the air-cleanliness class for each row or individual operating position and effectively define "zones" of air cleanliness in a horizontal flow room. Locating the "dirtiest" operations downstream nearest the exhaust area and staggering work locations are means of improving work station cleanliness levels in a horizontal flow room.

Other laminar airflow clean enclosures, i.e., benches, hoods, tunnels, curtained units, etc., may be verified for proper operation in essentially the same manner as outlined for laminar flow rooms except:

a. Open-faced units do not have an established pressure differential.

b. Temperature and humidity will be as controlled in the area in which the enclosûre is located, unless special facilities are provided.

c. Leaks in the enclosure walls, especially near the filter face, should be located and sealed to prevent inboard leakage of contaminants from the adjacent areas.

d. Shallow units such as benches and hoods should be checked for unusual air turbulence near the open face which may draw contaminated air into the work area.

5.12 Specifications for Laminar Airflow Clean Rooms

A definitive clean room specification is the result of careful planning and consideration of many factors which will dictate the features needed in a specific clean room installation. The primary consideration should be the <u>degree of air cleanliness needed</u> for the operations to be performed. Only after this point has been established can other decisions logically be made. A knowledge of the major room elements and their effect on clean room performance is essential for preparing a specification. This is also an influential factor in securing the most effective unit for the money expended.

Subsequent paragraphs are devoted to listing, and in some cases explaining, the items which should be considered in a clean room specification. This list may have to be expanded or reduced to accommodate specific situations.

5.12.1 General Specification Guidelines

a. Dimensions and Location -- A layout of the room and adjacent area should define the following features:

(1) inside dimensions of the room

(2) room connection points for service lines--water, gases, electricity, drains, vacuum, etc.

(3) maximum length, width, and height available within an existing structure

(4) general location within an existing structure

(5) type of existing structure--supported or free-standing, or if located outside any other building.

NOTE: The use of standard sized filters, filter modules, floor modules, and wall panels may result in lower costs, reduced lead time, and better quality construction.

b. Type of Room -- The type of room will reflect the air-cleanliness class needed and the operations to be performed. One of the following types will usually be specified:

(1) vertical airflow with full perforated floor exhaust

(2) vertical airflow with partial or perimeter floor exhaust

(3) vertical air downflow curtain units with perimeter exhaust

(4) limited vertical airflow with less than a full filter ceiling located above a perforated ceiling

(5) horizontal airflow with return duct location optional--above ceiling, below floor, or along side wall

(6) horizontal airflow tunnels with modular motor/blower/filter units and open-end exhaust.

c. Room Occupancy -- Specification planning should include an estimate of:

(1) the number of people normally occupying the room

(2) any abnormal amount of personnel movement in the room

(3) the amount of traffic in and out of the room.

d. Operations and Equipment -- Heat and contamination generating equipment as well as any unusual features should be noted. These may include:

(1) motors and other machinery

(2) ovens, vacuum chambers, sterilizer, etc.

(3) fume hoods, including the cfm of air exhausted.

e. Portability -- The specification should indicate whether the room is a permanent installation or if it should be of modular construction and have the capability to be dismantled and relocated.

f. Electrical Power Load -- Specify the following:

(1) maximum power required for operations within the room

(2) voltage, phase, and current requirements - 110, 220, and 440 volts, single or three phase, and AC or DC.

5.12.2 Performance Requirements

The performance requirements of a room should be specified in sufficient detail to assure the level of performance desired. It is recommended that the following items be included in any laminar airflow clean room specification:

a. Air-Cleanliness Class -- The class number listed indicates the maximum number of particles 0.5 micron and larger per cubic foot of air (FED. STD. 209a):

(1) Class 100

(2) Class 10,000

(3) Class 100,000

(4) other intermediate classes as needed.

b. Airflow -- While the airflow characteristics will be dictated generally by the type of room considered, the following parameters and their acceptable tolerances should be specified as applicable:

(1) velocity in feet per minute issuing from the filter bank

(2) air direction at specified points in the room

(3) air dispersion patterns in the unoccupied room.

c. Temperature -- Temperature requirements should include:

(1) temperature

(2) allowable tolerance

(3) specific location or zone in which readings will be taken

(4) expected heat dissipation from processing equipment.

d. Humidity -- Humidity requirements should specify:

(1) percent of relative humidity desired

(2) acceptable tolerance

(3) any conditions which would have an unusual effect on humidity control.

e. Lighting -- Lighting requirements may be specified as follows:

(1) fluorescent, incandescent, special

(2) minimum footcandles

(3) height and location(s) at which footcandle measurements will be made.

f. Noise and Vibration -- Stipulate maximum noise and vibration levels resulting from operation of the room itself (motors, blowers, air movement through ducts, etc.). These levels should not include noise or vibration produced by other equipment located in or outside the room.

5.12.3 Design and Construction Requirements

In order to achieve and maintain the performance requirements enumerated in the preceding paragraph, certain requirements concerning design, materials, and construction must be included in the specification. This paragraph suggests many of these items which might be included in a clean room specification.

a. General Requirements --

(1) The room must be airtight without the use of caulking or extensive use of mastic compounds. Mastic gaskets are acceptable.

(2) The room structure must be rigid to preclude the generation of contaminants due to structural vibration or movement.

(3) All interior surfaces in the room, return air ducts, and plenums should be fabricated from nonshedding materials and should have smooth surfaces with a minimum of interruptions.

(4) Metal surfaces should be stainless steel, finish grade, or painted with one coat of chromate primer and two coats of hard-gloss enamel or epoxy.

(5) All wood or composition surfaces shall be painted with one coat of primer and two coats of hard-gloss enamel or epoxy.

(6) All glass surfaces should be polished, laminated glass stock.

b. Walls --

(1) Permanent walls should be rigidly constructed with all exposed surfaces in the room properly treated.

(2) Modular metal walls should be so contructed that they may be disassembled for reuse without permanent damage.

(3) All walls should contain a vapor barrier.

(4) To the extent possible, all walls should be free of ledges, ridges, or other irregularities.

c. Ceiling - Vertical Laminar Airflow --

(1) The ceiling framework should be rigid metal construction, and designed to have HEPA filters installed and removed from inside the clean room.

(2) The ceiling framework should be equipped with pressure-locking devices to adequately seal the filter frame against air leakage.

(3) The ceiling framework should be free from air leakage and should be sealed around its own perimeter to prevent leakage of air between it and the walls.

(4) The ceiling framework should provide for the passage of electrical lines for the light fixtures.

(5) The ceiling framework should be designed to provide for mounting sprinkler heads on the room side of the module and connecting water lines to the heads. Each sprinkler head connection should be sealed to prevent air leakage.

d. Ceiling - Horizontal Laminar Airflow -- The ceiling may be any approved material, rigidly installed and sealed. Installation of lighting fixtures and sprinkler heads must not create any air leaks.

e. Ceiling - Perforated -- A perforated ceiling can be used to effect uniform air distribution when less than a full HEPA filter ceiling is required. This ceiling should be located below the structure in which the filters are mounted and should preferably be nonvibrating metal or plastic grille construction. A structural framework will be required to provide rigidity for the installation of lights and sprinkler heads.

f. Floor - Perforated or Grating --

(1) The floor module should be specifically designed to accommodate removable grating or perforated segments of a standard size to permit cleaning and interchangeability.

(2) The floor should be designed to support the anticipated loading without deflection.

(3) The floor support module may incorporate rough filters, louvers, vanes, or buffers below the openwork floor as an aid to maintaining an even airflow within the room.

g. Floor - Solid -- Masonry or wood floors should be covered with an easily cleaned low-shedding material, installed to eliminate cracks or openings in which dirt might lodge. Wood or wooden-supported flooring should be deflection free.

h. Plenum - Air Supply -- The materials employed in the construction of the air-supply plenum should be nonshedding, free of obstructions and rough surfaces, and adequate in size to permit proper dispersion of the air. In a horizontal installation, it should permit entry for cleaning or changing prefilters, if they are located in the plenum. It must be airtight.

i. Plenum - Exhaust --

(1) If leakage or spillage of liquids in the clean room is anticipated, the plenum material should be stainless steel or a material compatible with the liquids used.

(2) Joints must be airtight and access to the interior should be provided for cleaning.

(3) The exhaust plenum should be of sufficient depth to permit an essentially noiseless and uniform flow of air to the return air ducts.

j. Air Ducts --

(1) Whether fabricated ducts or wall sections are used as return air ducts, they must be airtight with smooth surfaces and joints. Ducts should be large enough to facilitate cleaning.

(2) Duct capacity should be adequate to carry the volume of air being handled at velocities less than that at which noise is generated.

(3) Bends in ducts should be gradual. All duct bends or turns should have a radius sufficiently large to prevent the generation of noise and heat.

k. Doors --

(1) All door edges, frames, and sills should be equipped with a continuous seal to prevent air leakage from the room due to the planned overpressure.

(2) A standard pressure door-closer, with enclosed mechanism, should be mounted outside the room to assure that the door will be closed.

5.12.4 Equipment Requirements

The following items should appear in the clean room specification only as they apply to equipment furnished by the room manufacturer. Otherwise, they represent standard clean room practice.

a. All equipment subject to maintenance and parts replacement should be a standard item, with replacement parts nominally available from manufacturer's stock.

b. All equipment installed within the clean room should be finished stainless steel or have a nonshedding surface.

c. All equipment employing drive mechanisms such as gears, chains, or belts should be fully enclosed to preclude releasing generated contaminants.

d. Equipment which may produce vibration must be factory precision balanced and equipped with vibration isolators. This specifically includes all motors, pulleys, sheaves, couplings, air-blowers, fans, impellers, and similar equipment.

e. All belts must be "V" type in matched sets.

f. All exposed rotating parts should be totally enclosed with removable guards. All guards should have openings opposite the end of rotating shafts to permit the use of a tachometer for measuring shaft speeds.

5.12.5 Electrical Requirements

Electrical installations should comply, as a minimum requirement, with the applicable rules of the National Electrical Code and any local codes, and all wiring should be in accordance with best industrial practice. All electrical material and equipment must be manufactured in accordance with NEMA Standards and must be Underwriters Laboratory labeled, if applicable.

a. Distribution Points -- The buyer shall provide power for lighting and other needs, at a point to be stipulated in the final installation contract.

b. Wiring -- All controls, control panels, and air-conditioning units should be factory-wired. Connections from controls, control panels, air-conditioning units, blowers, motors, and any other electrical equipment are generally wired by the room manufacturer. Conductors shall be continuous from outlet to outlet, and no splices shall be made except within outlet or junction boxes. Slack should be left in all pull boxes and at equipment to allow for neat, workmanlike terminations. A wire-pulling lubricant should be used when pulling conductors.

c. Wire Types and Sizes --

(1) All wire sizes should be specified American wire gage.

(2) All wire should be pure copper of the stated gage, with 98-percent conductivity.

(3) All wire insulation and size should be determined for each application and shall comply with applicable electrical codes.

(4) When heat is a factor, insulation should be heat-resistant Type THW.

(5) All wires for final connections to high-temperature devices (i.e., heating coils) should be Type AVA.

d. Conduit Systems --

(1) Conduit should be installed for connecting lighting fixtures, receptacles and switches, and extended to junction boxes located outside the clean room and to

the main supply system. Conduits should be concealed within walls and ceilings where feasible. Approved conduit locations should be shown on the installation drawings.

(2) Conduit should be galvanized and of appropriate size. Any conduit running inside the clean room should be painted with one coat of chromate primer and two coats of hard-gloss enamel or epoxy. Conduit which must be bent or formed should be painted after the forming is completed. All bends or offsets which cannot be avoided should be made with approved hickey or conduit-bending equipment. All conduit should be free of foreign matter and moisture when installed.

e. Lighting - Fluorescent --

(1) Light fixtures in vertical rooms should not be more than 6 inches wide.

(2) All fixtures should be equipped with thermally protected, automatic reset, Class A sound rated, high-power factor ballasts, UL and CBM approved, with an in-line fuse for each ballast.

(3) All fluorescent lampholders should be white phenolic compound, positive spring-action type. Interior wiring of all fixtures should be Type AF fixture wire of appropriate gage.

(4) Fixtures must be manufactured so that all parts will be continuously grounded. All fixtures and lamps shall be supplied and installed by the room manufacturer.

(5) Separate night-light switching and special lighting requirements should be specified.

f. Motor Controls --

(1) Magnetic motor starters should be installed in all cases where remote control is desired and "no voltage" or "undervoltage" protection is required. Two overload relays for installation of interchangeable overload relay heaters should be furnished with each starter.

(2) Combination starters with fused disconnect switches should be installed with fuse clips and fuses sized properly for the load.*

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*Protection Handbook of the Bussman Manufacturing Division, McGraw-Edison Company.

g. Electric Motors -- Electric motors should be of the continuous operation type, adequately sized, and precision-balanced at the factory (statically and dynamically).

h. Switches -- Control switches for the blower motor should be mounted on the control panel located outside the clean room. An emergency turn-off switch shall be located in the clean room, near the entrance door. If acids or other fume producing liquids are used in the clean room, an emergency turn-off switch shall be located adjacent to the position(s) where these liquids are used.

5.12.6 Air Filtration and Control System

The air filtration and control system concerns itself with cleaning and conditioning the clean room air and maintaining the conditions specified. It is related to but should not be confused with the air-handling system which includes the blowers, plenums, ducts, and baffles.

a. Rough or Ventilation Filters -- Being primarily intended to remove contaminants of gross sizes, the material selected for rough filtration should be nonshedding, inexpensive, and easily changed or removed for cleaning or replacement. It is not advisable to select a loosely packed fibrous-type (home furnace-type) filter. A controlled open-pore structure urethane is recommended. This material is inexpensive, may be washed in a detergent, retains its resilience, and in the 20-cell type is reasonably efficient for gross contaminants.

b. Prefilters -- The purpose of prefilters is to sustain the life of the more expensive HEPA filters. The selection of the efficiency level for prefiltration, therefore, is directly related to the contaminant level of the air. The efficiency of prefilters used for a clean room is dependent on the amount of air recirculated and the contamination generated within the room. Filter efficiencies are directly related to cost and pressure drop which will increase as the efficiency increases. Prefilters are available with efficiency ratings from 45 to 95 percent by the weight or synthetic dust test method.

c. Final Filter - High Efficiency Particulate Filter (HEPA) -- Generally, the manufacturers of HEPA filters each have individual identification systems, but all make essentially the same type filters. When ordering HEPA filters, the purchase order should stipulate on the face of the order that they are for "Laminar Airflow Clean Room Installation." This will alert the manufacturer that stock filters should not be supplied for that specific order.

Each manufacturer publishes a specification for his own filters. If a specific manufacturer is selected, reference should be made to that manufacturer's printed specification by number.

The following basic information is provided to define 5-7/8 inch deep HEPA filters in a specification. Filters of other dimensions should be defined accordingly.

(1) Filters should be individually 100-percent tested and certified leak-free (FED. STD. 209a) and must have an efficiency of not less than (99.97) (99.99) (99.999) when tested with 0.3-micron dioctylphthalate smoke. The clean filter pressure drop should be no greater than 1 inch WG (1.25-inch WG for 99.999) when operating at a nominally rated capacity of 150 cfm/ft^2 of filter area with a 5-7/8 inch deep filter. Average ratings are:

    24 x 24 x 5-7/8 in. is rated at 600 cfm
    24 x 30 x 5-7/8 in. is rated at 750 cfm
    24 x 36 x 5-7/8 in. is rated at 900 cfm
    24 x 48 x 5-7/8 in. is rated at 1230 cfm.

(2) Filters must be factory constructed by pleating a continuous sheet of 100-percent glass media into closely spaced pleats, with corrugated (Kraft paper) (aluminum) (plastic) separators inserted between each fold of the pleated media.

(3) The media/separator assembly should be installed in a rigid holding frame with overall frame dimensions held to ±1/16 inch, and squareness to within 1/8 inch. The rubber base sealer, providing a leak-free bond between the media and the frame should be resilient and self-extinguishing.

(4) The material used for the separator and frame should be selected to meet the humidity and fire-resistant requirements of the specific installation. Kraft separators and a plywood frame will produce a flammable filter and will break down at more than 80% RH. Aluminum separators and exterior fire-resistant plywood frame will produce a reduced fire hazard and will increase the moisture resistance to 100% RH. Aluminum separators with aluminum or steel frames are fire-resistant and will withstand 100% RH.

d. Clean Room Filter Bank Pressure Gages -- There are three commonly used types of gages employed to provide filter bank pressure-drop measurement. A specification for each type of gage should include information as follows:

(1) Flex-Tube Manometer -- A manometer mounted in a convenient location on each filter bank should be complete with pressure fittings for duct and flexible double column plastic tubing. The pressure range scale should be from 0 to 3 inch WG static pressure.

(2) Inclined-Tube Air-Filter Gage -- An inclined-tube air-filter gage mounted on each filter bank should include 3-way vent valves, be of solid acrylic plastic construction with built-in level vial, should have an adjustable scale and should be furnished complete with aluminum tubing, static pressure tips, and mounting assembly. The gage should have a pressure-drop range of 0 to 3 inch WG static pressure.

(3) Magnehelic Pressure Gage -- A magnehelic differential pressure gage mounted on each filter bank should be of the diaphragm actuated, dial type with 3-7/8 inch diameter white dial with black figures, and graduations should have pointer zero adjustment. It should be furnished complete with aluminum tubing, static pressure tips, and mounting assembly. The gage should have a pressure-drop range of 0 to 3 inch WG static pressure.

e. Air Conditioning -- Specifying requirements for air conditioning involves many variable factors such as mean local temperatures, humidities and elevation, and room size or demand. However, some points which should be considered are:

(1) Air conditioning for the clean room may need to be completely independent of the regular plant system.

(2) If the clean room is to encompass operations which will require some equipment to be operated continuously, some provision should be made for auxiliary cooling in the event of any equipment failure.

(3) The selection of the unit capacity should include a safety factor, which would depend upon the climate zone.

5.12.7 Applicable Standards

Standards, specifications, and codes prepared by the following groups may be useful in preparing clean room specifications:

Air Conditioning and Refrigeration Institute - ARI

Air Moving and Conditioning Association - AMCA

American Society of Heating, Refrigeration and Air Conditioning Engineers - ASHRAE

American Society of Mechanical Engineers - ASME

American Society for Testing and Materials - ASTM

General Services Administration - GSA (Fed. Std. 209a)

National Electrical Manufacturers Association - NEMA

National Fire Protection Association - NFPA

Sheet Metal and Air Conditioning Contractors National Association, Inc. - SMACNA

Underwriters' Laboratories, Inc. - UL

United States of America Standards Institute - USASI

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SECTION 6

MICROBIAL CONTAMINATION AND ITS CONTROL

Microorganisms occur nearly everywhere in nature. They are found in sediments from the ocean's bottom, on mountain heights, and may be carried by air currents to the upper atmosphere. The soil teems with them. They occur most abundantly where they find food, moisture, and a temperature suitable for their growth and multiplication. These conditions are generally those under which man lives; therefore, we live among a multitude of microbial forms and types. They are in the air we breathe, the food we eat, on our body surface, and in our intestines and body openings. Microbes outnumber all other types of living organisms on earth. A cup of ordinary garden soil contains more microorganisms than there are people on earth.

One microbial form--the bacterial spore--is recognized as the most resistant of all living organisms to adverse environmental agents.

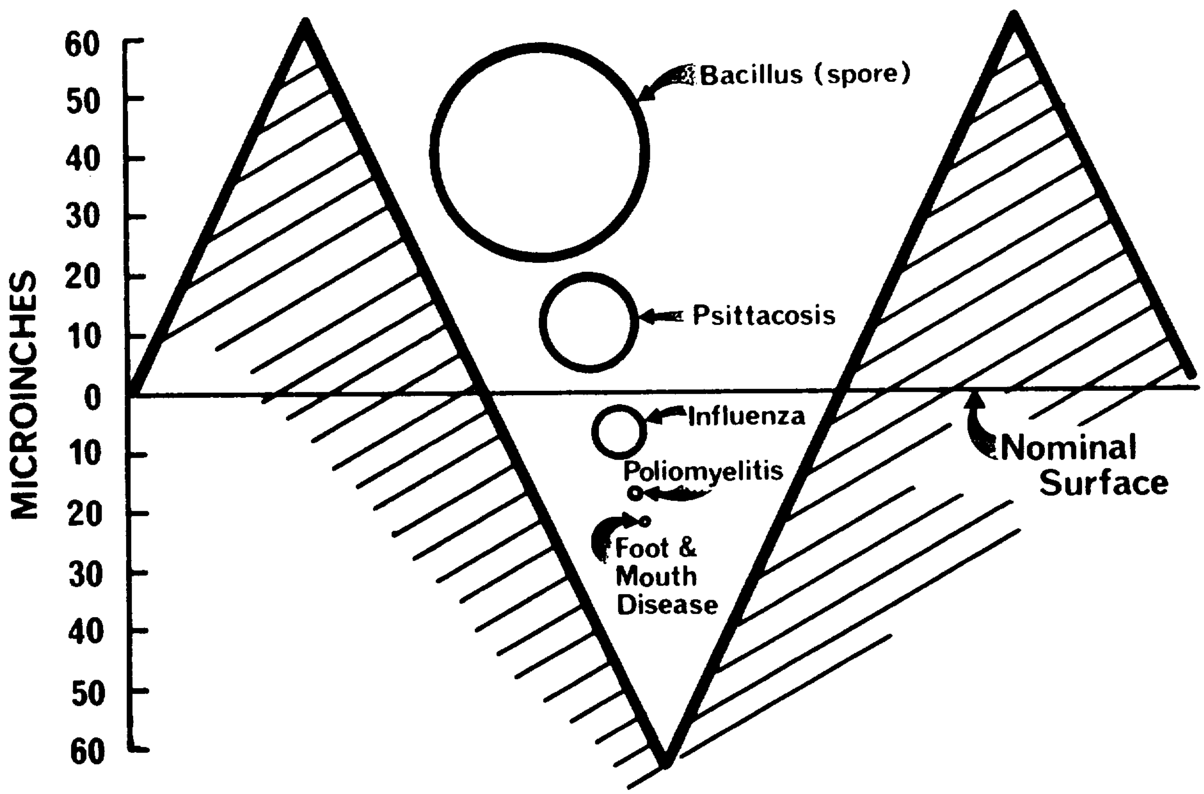
Microorganisms react to the physical laws like any other small particle except that they are able to reproduce. Bacterial cells are normally negatively charged. Some physical characteristics are presented in Table 6-1. The size relationship of a microbe to a machined surface may be seen in Figure 6-1.

TABLE 6-1

Physical Characteristics of Microbial Cells

Microorganism	Volume	Surface Area	Density	Particle Weight	Refractive Index
Escherichia coli	$0.52\text{-}1.7\mu^3$	$3.1\mu^2$	1.0-1.25	5.6×10^{-13} gm	1.40
Bacillus (spore)	$1.18\mu^3$	$4.72\mu^2$	1.28	15.1×10^{-13} gm	1.50

Water is the most abundant compound in all living things. Cells may survive without much water (20-30 percent by weight); however, they cannot function without it. Water is the solvent for food intake and waste removal from cells; it is an integral part of all cellular processes. The general chemical constituents of living matter are summarized in Table 6-2.



Source: Biological Handbook for Engineers, Marshall Space Flight Center, NASA, 31 March 1968.

Figure 6-l. Relationships between a machined surface (43 rms) and different organisms

TABLE 6-2

Typical Chemical Constituents of Living Matter

Chemical	Cellular Composition (% by weight)
Water	77
Protein	15
Fat	5
Carbohydrate	2
Other	1

Microbial contamination could be described as the occurrence and persistence of minute organisms in specified environments where they are not wanted. Microbial contamination poses special problems of control, since microorganisms have the ability to grow, reproduce, and carry on physiological processes under unusual conditions. Viable particulate material may become a large biomass if the necessary growth requirements are supplied by the environment. Products of metabolic activity may be corrosive or otherwise deleterious.

In the world of microbes, the organisms recognized as causing the greatest problems in contamination control are the bacteria and fungi. These groups have been more thoroughly studied, they are easier to work with in the laboratory, and they are the most hardy of the microorganisms (containing spore forming types). These two groups of organisms fall more into the context of this handbook and are therefore emphasized more than the other groups, i.e., viruses, rickettsia, algae, and protozoa.

6.1 Characteristics of Microbial Contamination

6.1.1 Physical

Groups generally considered as microorganisms include the viruses, rickettsiae, bacteria, fungi, protozoa, and algae. Microorganisms may differ over a wide range of dimensions. Figure 6-2 illustrates the size relationships of these organisms.

The viruses are the smallest of all biological entities and they vary generally from 8 to 10 millimicrons (mμ) to 250 to 300 mμ. One micron (μ) is equal to 1/1000 mm; 1 mμ is 1/1000 μ. The viruses are obligate intracellular parasites, i.e., they require a living host cell.

The rickettsiae are similar to the bacteria in many respects; they are about the size of the smallest bacteria. The rickettsiae are also obligate intracellular parasites.

The bacteria may occur as single cells (Figure 6-3) but in most cases they occur in clumps, chains, filaments, plates, or compact aggregates. The individual cells may be rod-shaped (cylindrical), coccoid (spherical), or spiral-shaped. The bacteria vary in size from less than 1 μ to filamentous forms as long as 100 μ. Many bacteria are endowed with fine surface filaments (flagella) which give them a certain amount of self-powered motility. This motility is relative to their size and the environment. The molecular oxygen requirement of the bacteria varies from aerobic organisms (which require molecular oxygen) to the obligate anoerobic organisms (for which molecular oxygen is toxic). Bacteria reproduce by cell division; a very effective process. Some bacteria can divide every 20 minutes, thus a single bacterium under continuing optimal conditions would give rise to one million offspring in 6 to 7 hours, and in 48 hours the mass of bacteria would be 4000 times the mass of the earth. On occasion, certain bacteria form heavy walls (spores) (Figure 6-4), and in this state they are very resistant to adverse environmental conditions.

The fungi are a heterogenous group made up of such diverse forms as yeasts, molds, mildews, and mushrooms. The yeasts are somewhat larger (5 to 10 μ) than most bacteria, but they are still relatively small when compared to the molds, protozoa, or algae. Molds generally grow in filaments, or hyphae, which in turn comprise the body of

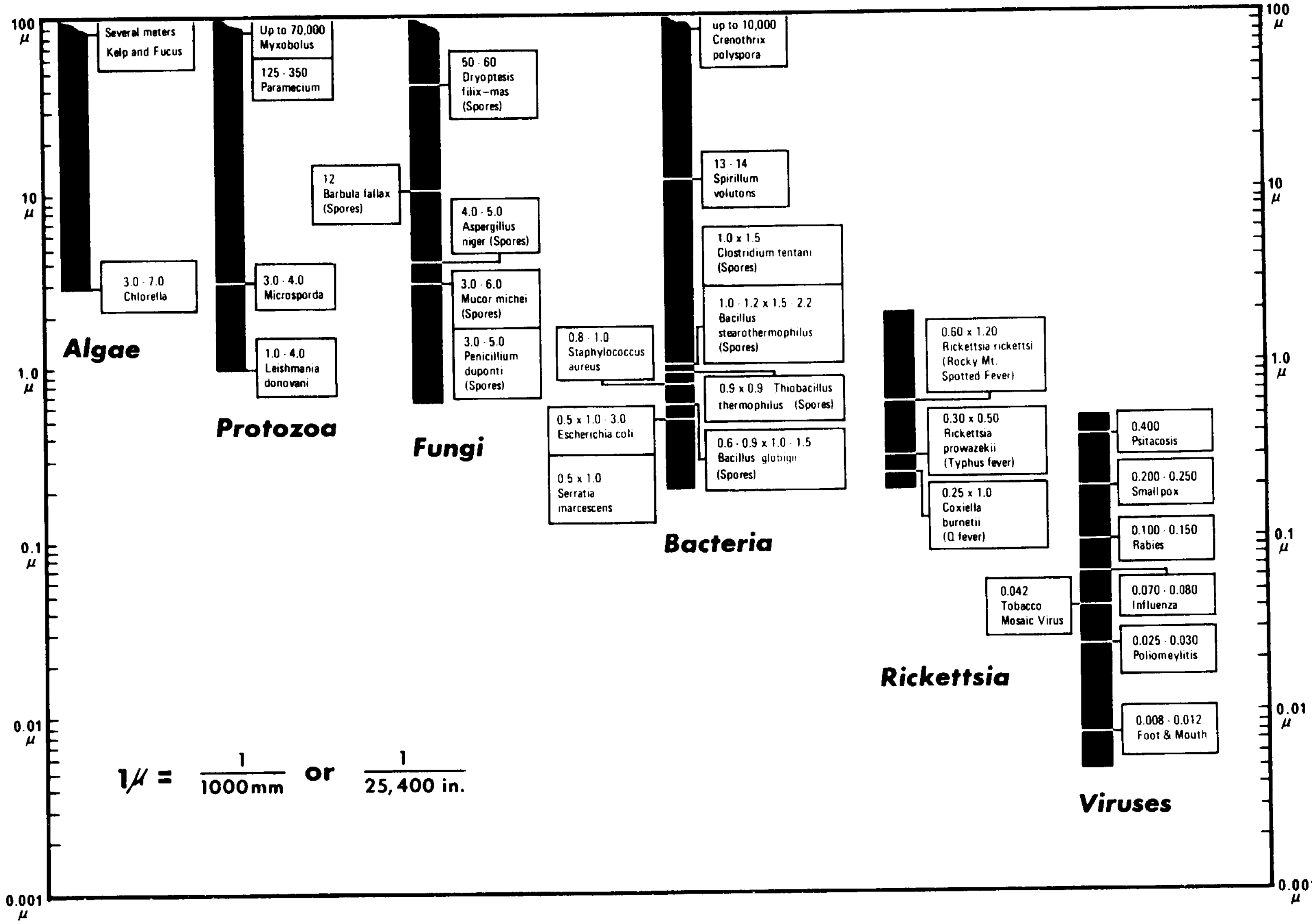


Figure 6-2. Relative sizes of microorganisms

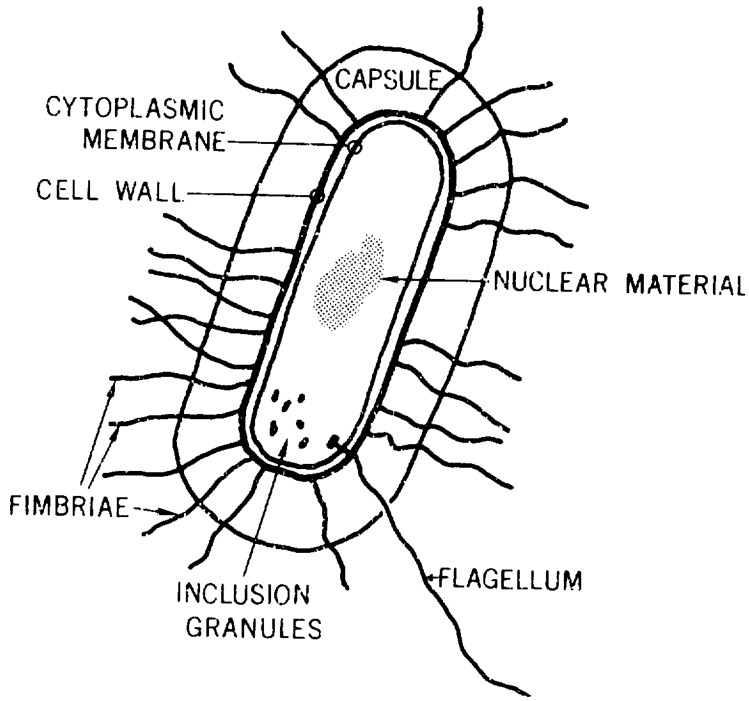


Figure 6-3. Diagram of a typical bacterial cell

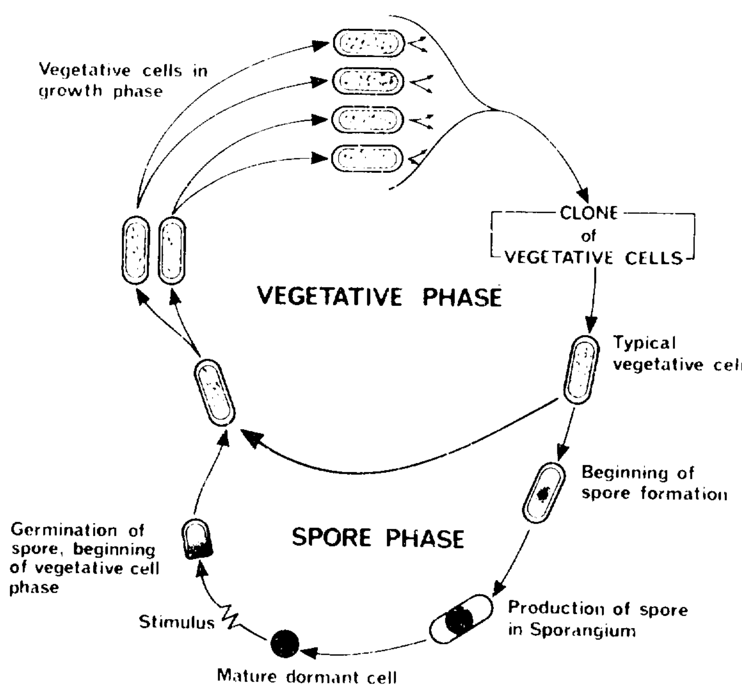


Figure 6-4. "Life cycle" of spore-formers

the organism, the mycelium. The mold hyphae have diameters of 2 to 200 μ but may have lengths of many millimeters. The mycelium consists of a macroscopic structure which may be quite large. It should be emphasized that the mycelium (hyphae) may fragment and that the smaller particles can grow and regenerate the plant, given the necessary growth conditions. Mold spores are considerably larger (4 to 100 μ) than the bacterial spores. They will, however, sometimes stay suspended in the air for long periods of time, especially if they have planar surfaces.

The protozoa are found in water or in the animal body and, consequently, might be a problem only in situations involving the contamination of such fluids. Protozoa which become suspended in the air would necessarily settle rapidly because of their droplet size. Protozoa are highly susceptible to drying. Certain parasitic protozoa do form resistant cysts, but these are not nearly as resistant as the spores of bacteria and molds.

The algae vary widely in size from the microscopic blue-green algae to the macroscopic brown algae (seaweed) which may grow to a length of 100 feet or more. The algae live and grow in water and on moist surfaces. The smallest algal cells are approximately 1 to 2 μ in diameter. Some algae, such as the diatoms, form mineral shells (calcium carbonate) and may be very resistant to harsh environmental conditions.

6.1.2 Metabolic or Nutritional Types

All biological systems from microorganisms to plants and man share a set of physiological and nutritional requirements which are necessary for growth and reproduction (Figure 6-5 and Table 6-3).

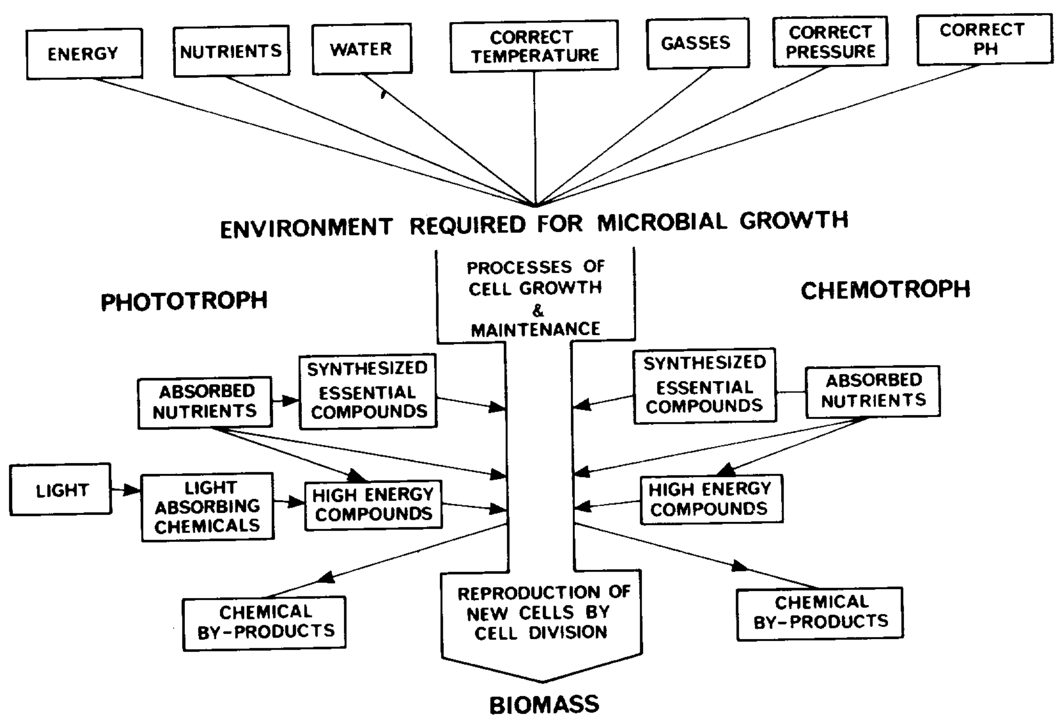


Figure 6-5. Microbial growth

TABLE 6-3

Physiological and Nutritional Requirements of Biological Systems

Element	Function
Water	The universal biological solvent. Nutrients must be dissolved before they can be utilized by the cell. Enzymatic reactions occur in the presence of water.
Energy	Some utilize light energy while other systems depend on oxidation of chemical compounds. All must have an energy transfer system.
Carbon	This may be in the form of CO_2, carbonate, or more complex organic molecules, i.e., sugars, fats, or amino acids.
Nitrogen	Microorganisms are extremely versatile in this regard. Some fix atmospheric nitrogen; others utilize ammonium, nitrate, nitrite, and still others <u>require</u> more complex forms, i.e., amino acids.
Sulfur	This requirement may be elemental sulfur but is often supplied as inorganic or organic compounds.
Phosphorus	Usually supplied as a phosphate.
Metallic Elements	Diversity not well defined. Frequently require only trace amounts, i.e., sodium, potassium, iron, zinc, calcium, magnesium, manganese, copper, and cobalt.
Vitamins	These are molecules of varying complexity acting chiefly as parts of enzymes or other biological catalysts.

<u>Autotrophic</u> organisms are very complex and complete in their enzymatic properties, but they are sometimes extremely simple in their nutritional requirements. Autotrophs have the unique characteristic of being able to utilize carbon dioxide as a <u>sole</u> source of carbon. Autotrophs grow and reproduce when supplied with carbon dioxide (or carbonate) and a few simple inorganic salts. They obtain their energy either from light (phototrophs) or from the oxidation of inorganic compounds (chemotrophs). Some examples of autotrophic bacteria are given in Tables 6-4 and 6-5.

<u>Heterotrophic</u> organisms are <u>unable</u> to utilize carbon dioxide (or carbonate) as a <u>sole</u> source of carbon but must be supplied with an organic carbon source. The heterotrophs vary widely in their nutritional requirements; from an organism requiring a single organic compound plus a few simple salts to one which requires such additional growth factors as metabolites and vitamins. The extreme diversity in the nutritional requirements of the heterotrophs can be seen in examples given in Tables 6-4 and 6-5.

TABLE 6-4

Bacterial Spore-Formers

Genus	Spore Size, Shape	Nutritional Type	Optimum Growth Temperature	Oxygen Requirement	Habitat	Motility
Clostridium tetani	1.0-1.5 μ diameter; spherical	Heterotroph	37°C	Anaerobic	Soil, feces of herbivora	Yes
Clostridium botulinum	Ovoid	Heterotroph	25°C	Anaerobic	Soil, decayed vegetables	Yes
Clostridium perfringens	Ovoid	Heterotroph	35°-37°C	Anaerobic	Dust, soil, sewage, water fish, milk, feces of animals and man	No
Clostridium chauvoei	Ovoid	Heterotroph	37°C	Anaerobic	Soil	Yes
Clostridium novyi	Large, ovoid	Heterotroph	35°-38°C	Anaerobic	Soil	Yes
Clostridium butyricum	Oval	Heterotroph	30°-37°C	Anaerobic	Soil, naturally soured milk, naturally fermented starchy plant substances	Yes
Clostridium sporogenes	1.0 by 1.8 μ; ovoid	Heterotroph	37°C	Anaerobic	Soil	Yes
Thiobacillus thermophilica	Oval	Autotroph	55°-60°C	Aerobic	Deep waters, volcanic muds, mineral springs soil, atmospheric dust	Yes
Streptomyces albus	1.0 by 1.5 μ; ellipsoidal	Heterotroph		Aerobic	Soil	
Streptomyces griseus	0.8 μ by 0.8 to 1.7 μ; spherical to ellipsoidal	Heterotroph	37°C	Aerobic	Soil	
Bacillus megaterium	1.0-1.2 μ by 1.5-2.0 μ; ellipsoidal	Heterotroph	28°-35°C	Aerobic	Soil, water, dust-decomposing materials	Yes
Bacillus cereus	1.0-1.5 μ; ellipsoidal	Heterotroph	30°C	Faculatively anaerobic	Soil, dust, milk, plant surfaces	Yes
Bacillus subtilis	0.6-0.9 μ by 1.0-1.5 μ; ellipsoidal to cylindrical	Heterotroph	28°-40°C	Aerobic, certain strains faculatively anaerobic	Soil, decomposing organic matter	Yes
Bacillus coagulans	0.9-1.0 μ by 1.2-1.5 μ; ellipsoidal	Heterotroph	33°-45°C	Faculatively anaerobic	Spoiled food, cream, cheese, and silage	Yes
Bacillus stearothermophilus	1.0-1.2 μ by 1.5-2.2 μ; ellipsoidal	Heterotroph	50°-65°C	Faculatively anaerobic	Soil, spoiled food products	Yes

TABLE 6-5

Bacterial Nonspore-Formers

Genus	Size (μ)	Nutritional Type	Optimum Growth Temperature	Oxygen Requirement	Habitat	Motility
Pseudomonas aeruginosa	Rods, 0.5-0.6 by 1.5 μ	Heterotroph	37°-42°C	Faculatively anaerobic	Polluted water, sewage	Yes
Micrococcus roseus	Spheres, 1.0-1.5 μ	Saprophytic, heterotroph	25°C	Aerobic	Dust	No
Staphylococcus aureus	Spheres, 0.8-1.0 μ	Heterotroph	37°C	Faculatively anaerobic	Nasal mucous membrane and skin	No
Serratia marcescens	Rods, 0.5 by 0.5-1.0 μ	Saprophytic, heterotroph	25°-30°C	Faculatively anaerobic	H_2O, soil, milk, foods, silk worms, other insects	Yes
Sarcina lutea	Spheres, 1.0-1.5 μ	Saprophytic and faculative, heterotroph	25°C	Aerobic	Soil, water, skin surfaces	No
Streptococcus faecalis	Spheres, ovals of variable size	Heterotroph	37°C	Faculatively anaerobic	Intestines of humans and other warm-blooded animals	No
Streptococcus thermophilus	Spheres, 0.7-0.9 μ	Heterotroph	40°-50°C	Faculatively anaerobic	Milk and milk products	No
Escherichia coli	Rods, usually 0.5 by 1.0 to 3.0 μ	Heterotroph	30°-37°C	Faculatively anaerobic	Intestines of man and other vertebrates	Motile and non-motile strains

Obligate intracellular parasites such as all of the viruses (plant, animal, and bacterial), the rickettsiae, and perhaps a few of the bacteria must be cultured in living cells; i.e., they cannot be grown in a cell-free medium. Their nutritional and metabolic requirements are so complex and extreme that, as yet, they have not been cultivated successfully outside the living cell.

The viruses are quite different from any other organisms. The infective (cell penetrating) unit of the virus is a nucleic acid (ribonucleic acid or deoxyribonucleic acid, depending on the virus). When the viral nucleic acid enters the susceptible host cell, it takes over the genetic mechanism (cell sustaining and perpetuating processes) of the host cell and diverts the host cell metabolic processes to the manufacture of new viral particles. This may continue until the host cell bursts (as with bacterial viruses) or the complete virus may escape from the host cell gradually (as with many animal viruses).

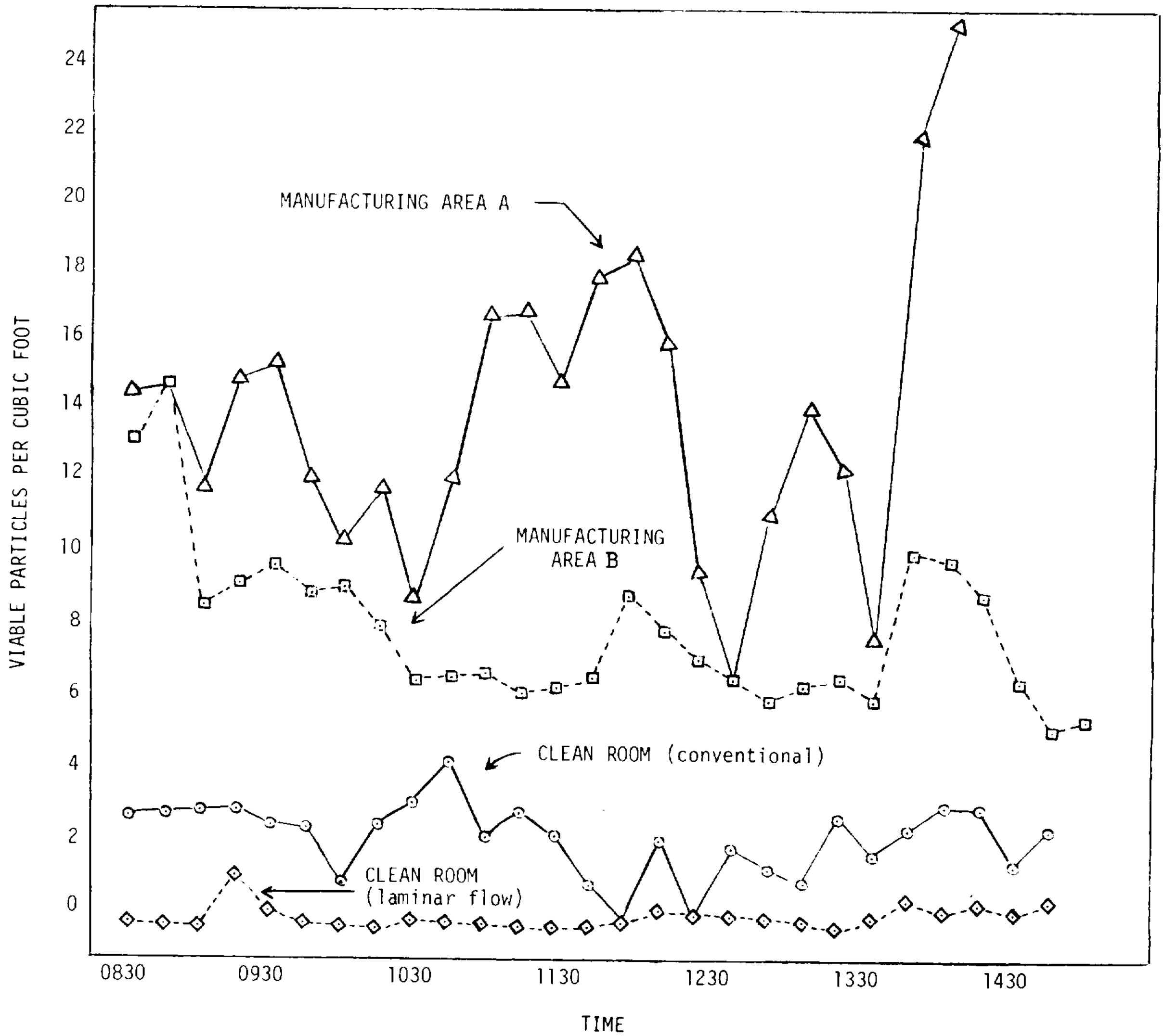
The rickettsiae seem to be much like the bacteria, except for their adaptation of intracellular parasitism. It has also been demonstrated that the rickettsiae do have intrinsic metabolic activities, and they are sensitive to the broad-spectrum antibiotics--points which clearly make them different from the true viruses. They divide in the same manner as bacteria (transverse binary fission), they have a cell wall, their chemical constituents appear to be very similar, and they are about the same size.

6.1.3 Microbial Flora of Selected Environments

a. Clean Rooms -- The microbial flora of a clean room is directly related to the environment, activity, density of personnel, and longevity of the microbes in the environment. As the environment and personnel are controlled with respect to reduction of particle contamination, the levels of microbial contamination are also reduced. The main source of viable contamination is associated with the density and activity of the personnel.

   Particulate microbial contamination is different from other particulate contamination only in its viability. These particles all react in essentially the same way to the physical laws. Only when particles are placed in a nutrient environment are the viable differentiated from the nonviable. Microorganisms in a particulate state are thought to be present usually as agglomerates or affixed to larger particles. Figure 6-6 and Tables 6-6 and 6-7 are examples of the microbial flora of a clean room.

b. Various Body Areas -- Table 6-8 serves to indicate the more prevalent (or normal) organisms found on various body areas. This flora is a function of the individual and his "immediate" history, thereby indicating a dynamic state about a norm. This normal flora resides in the deeper skin layers (sebaceous glands and hair follicles) rather than on the skin surface. However, organisms are usually shed with or attached to skin scales. It has been shown that shower bathing causes an approximate five-fold increase in shedding of microorganisms. This high population returns to normal in 1 to 2 hours.



Source: "Environmental Microbiology and the Control of Microbial Contamination," Spacecraft Sterilization Technology, NASA SP-108, 1965.

Figure 6-6. Comparative levels of airborne microbial contamination

TABLE 6-6

Types of Microorganisms (Aerobic, Mesophils) on Surfaces in Various Environments

Type of Microorganism	Percentage of Total Microorganisms Observed		
	Conventional Clean Room	Laminar Flow	Manufacturing Area
Staphylococcus aureus	0-0.5	0-0.5	0
Staphylococcus epidermidis	1.9-47	23-33	13-15
Micrococcus spp.	4-9	5-8	2-6
Streptococcus spp.	0-3	0-1	0-2
Bacillus spp. (sporeformers)	10-56	32-35	21-31
Corynebacterium spp.	14-36	9-21	10-24
Gram negatives	0	0-0.5	0-15
Yeasts	0-2	1-2	1-2
Molds	3-13	11-12	24-25
Actinomycetes and streptomycetes	1-6	2	2-7
Unidentified	0-3	0	0

Source: "Environmental Microbiology and the Control of Microbial Contamination," *Spacecraft Sterilization Technology*, NASA SP-108, 1965.

TABLE 6-7

Spore-Forming Bacterial Species Isolated in Conventional Clean Rooms

Species - in order of prevalence
Bacillus subtilis
Bacillus pumilus
Bacillus megaterium
Bacillus cereus

TABLE 6-8

Prevalent Microbial Flora (Genera) of Various Body Areas

Body Area	Organism	
Scalp		
	Staphylococcus	spp.*
	Corynebacterium	spp.
	Gram positive rods	
Ear		
	Staphylococcus	spp.
	Corynebacterium	spp.
	Bacillus	spp.
	Gram positive rods	
Eye		
	Staphylococcus	spp.
	Micrococcus	spp.
	Gram positive rods	
	Enteric org.	
Nose		
	Staphylococcus	spp.
	Corynebacterium	spp.
	Penicillium	spp.
	Gram positive rods	
Mouth		
	Streptococcus	spp.
	Staphylococcus	spp.
	Neisseria	spp.
	Corynebacterium	spp.
Throat		
	Streptococcus	spp.
	Neisseria	spp.
	Lactobacillus	spp.
	Staphylococcus	spp.
Forearm		
	Staphylococcus	spp.
	Bacillus	spp.
	Lactobacillus	spp.
	Corynebacterium	spp.
Hand		
	Staphylococcus	spp.
	Bacillus	spp.

*spp. - abbreviation for species

c. Jet Fuel -- Microbial contamination of fuel facilities comes from the soil or air (Table 6-9). The growth requirements (generalized in Table 6-3 and Figure 6-5) are provided by the fuel, dissolved water, and particulate contamination. As growth proceeds, a biomass (sludge or mat) is produced, along with by-products of metabolism (organic acids) which may cause pitting or etching of a metal (Figure 6-7). Metal corrosion may also be produced by the electrolytic ion transfer as the microorganisms metabolize available elements. The presence of spore-forming bacteria in fuel facilities is presently the index of contamination. However, the presence of fuel utilizers (hydrocarbon hydrolyzing microorganisms) may be a much better index to potential problems.

TABLE 6-9

Microorganisms in Jet Fuels

Common Isolates	Other Isolates
Bacteria Bacillus spp. Pseudomonas aeruginosa Aerobacter aerogenes Fungi Cladosporium spp.	Clostridium spp. Spicaria spp. Fusarium spp. Micrococcus spp. Sphaerotilus spp. Penicillium spp. Aspergillus spp.

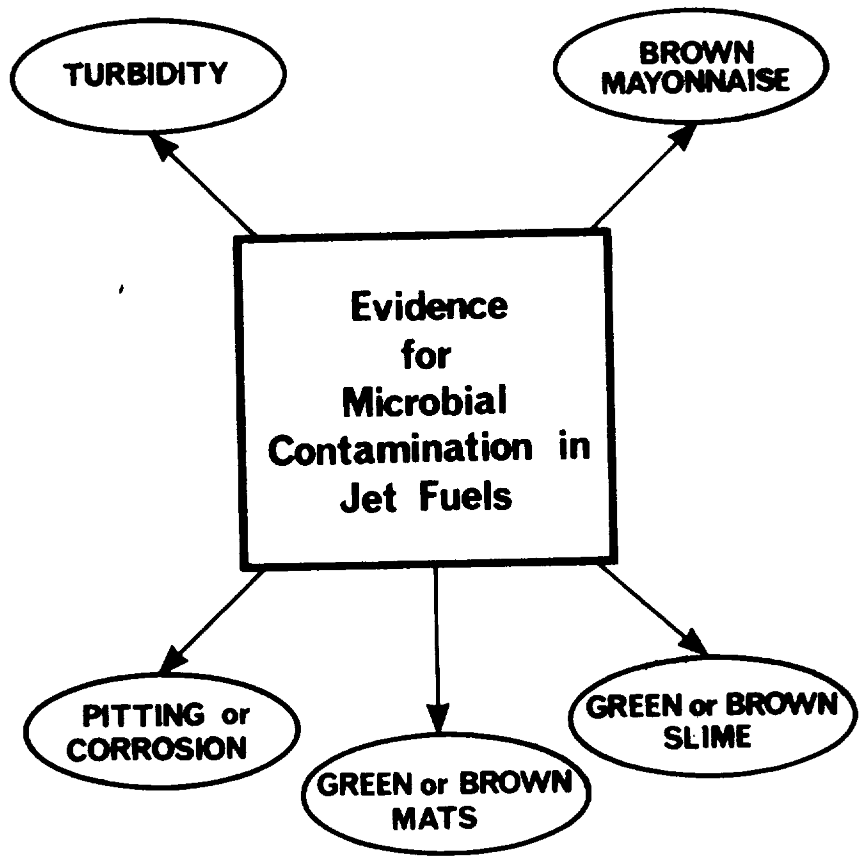


Figure 6-7. Examples of commonly encountered contaminants of jet fuels

Many microorganisms by themselves are unable to grow and reproduce in fuels. However, when certain types coexist in fuel facilities, a symbiotic relationship may be set up among or between various fungi, anaerobic bacteria, and aerobic bacteria. This relationship creates growth conditions beneficial to all the organisms involved. The fungi serve to give rigidity to the biomass.

It should be noted that the contamination of fuels is a result of small viable particulate contaminates common to the soil and air (Tables 6-10 and 6-11).

TABLE 6-10

Microorganisms in Various Environments

Environment	Quantity of Microorganisms
Soils	10^4-10^{10} per gram
Water	<1-10^4 per gram
Air	10^1-10^5 per ft^3
Stratosphere	1-10^{-3} per ft^3
Human skin	1-10^4 per in.^{2}
Floors	10-10^3 per in.^{2}

TABLE 6-11

Variety of Microorganisms per Gram of Soil

Microorganism	Range
True Bacteria	10^6-10^{10}
Actinomycetes	10^5-10^7
Protozoa	10^4-10^6
Algae	10^3-10^5
Molds	10^3-10^5

d. Microbes in the Earth's Atmosphere -- The boundaries of microbial ecology at the extreme environmental limits for earth have not been well established. The air close to the earth's surface may contain 100 or more microorganisms per cubic foot. During dust storms, the number increases dramatically. To date, estimates of the upper boundary altitude range of the terrestrial biosphere are lacking.

The earth's atmosphere is a multiple mixture of churning gases and trace amounts of liquids and solids. The prime force producing changes in the upper atmosphere is the radiant energy of the sun. To remain viable, microorganisms in the upper atmosphere must survive the sun's radiant energy and ionized molecules, as well as vacuum and a steady shower of meteoric debris. According to available laboratory data it seems probable, given a slight amount of shielding (dust-borne viable particles), that microorganisms can survive the upper atmospheric conditions. Since this is a harsh and "lethal" environment, growth and multiplication under such conditions would be impossible.

Explanations for the presence of microorganisms at altitudes greater than 100,000 feet may be volcanic eruption, nuclear explosions, activities of man in space, and upper atmospheric exploration. Even more intriguing is the concept that life pervades the universe.

Fungi, primarily *Altenaria* spp and *Cladosporium* spp, along with one bacterial genus (*Micrococcus*), predominate at the highest altitudes sampled. The low density of microorganisms at high altitudes is seen in Table 6-12. The difficulty of analyzing small numbers of microbes should be emphasized.

TABLE 6-12

Density of Microorganisms at Various Altitudes

Altitude	Approximate Density of Microbes
30,000-60,000 ft	2 or 3 x $10^{-3}/ft^3$
60,000-90,000 ft	1 to 5 x $10^{-4}/ft^3$

6.2 Control of Microbial Contamination

The death rate of microorganisms under the influence of an antimicrobial or lethal agent (Table 6-13) generally follows an exponential form (Figure 6-8). This is observed in chemical reactions where it is referred to as unimolecular or first order.

Conditions influencing antimicrobial action

- Concentration and type of chemical agent
- Intensity and nature of physical agent
- Time
- Temperature
- Number of organisms
- Type of organism

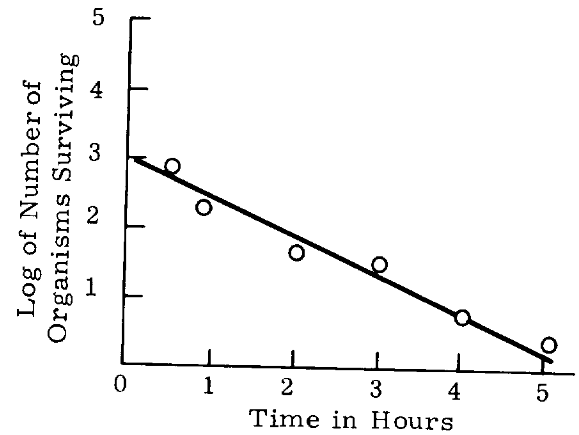


Figure 6-8. Logarithmic death curve

TABLE 6-13

Some Recommended Agents and Treatments for Sterilization or Decontamination

Sterilization or Decontamination Agent	Recommended Treatments	Remarks and Limitations
Moist heat (autoclave)	121°C, 15-20 minutes	Variations in time and temperature may be useful. Material must be permeable to steam but not damaged by it.
Dry heat	160°C, 2 hours	Other combinations of time and temperature are acceptable.
Ethylene oxide gas (in nonexplosive mix)	25°C, 30-percent RH 300 mg/1, 8-16 hours	Will not penetrate solids absorbed in rubber and plastics. Requires thorough aeration due to its toxicity.
Peracetic acid spray	25°C, 2 percent with 0.1 percent surfactant, 20 minutes	Corrodes metals.
Steam-formaldehyde	25°C, RH above 80 percent 1 ml/ft^3	Formaldehyde polymerizes on surfaces, requiring aeration and cleaning.
Beta-propiolactone	25°C, RH above 70 percent 200 mg/ft^3	Requires aeration due to its toxicity.
Dunkbath formalin (37-percent HCHO)	25°C, 10 percent, 10 minutes	Irritating fumes.
Sodium hypochlorite	25°C, 500-5000 ppm with 1-percent surfactant, 5 minutes	Corrodes many metals.
Ultraviolet radiation	25°C, 800 microwatt minutes per cm^2	Very low penetration. Limited to clean and exposed surfaces and air.

The cultural conditions of a microorganism before treatment, the conditions of the actual treatment, and the conditions of the recovery can affect the lethal activity, real or apparent. Three examples will serve to clarify the above:

a. <u>Before Treatment</u> -- The temperature at spore formation can affect the heat resistance of the spore.

b. <u>Actual Treatment</u> -- The presence of organic material will bias (absorbs chemical) results of certain chemical disinfectants.

c. <u>Recovery</u> -- One medium may give no growth, whereas another will support growth; hence, "sterility" is observed with the one medium but not the other.

6.2.1 <u>Deactivation</u>

The three main subdivisions discussed in deactivating microbial cells are heat, chemicals, and radiation. The circumstances requiring the control or deactivation will determine the type of energy or agent to be used. Of these three means of deactivation, only the application of heat has the practical potential for rendering a mass sterile.

a. <u>Heat</u> -- The metabolic activities of microorganisms are the result of chemical reactions which are influenced by changes in temperature. Each microorganism has an optimum, a minimum, and a maximum temperature for growth. Temperatures below the minimum will have a static effect (low temperatures preserve organisms) and those above the maximum will have a -cidal or killing effect. Heat is the most widely used sterilizing agent because it is reliable, efficient, and easy to measure. The application of heat (to sterilize) has two major subdivisions: moist (steam under pressure; autoclave) and dry. Moist heat is the more efficient of the two at equivalent temperatures (Table 6-14).

<u>Moist Heat</u>

- Great penetrating power compared to dry heat
- Destroys microorganisms by coagulation of proteins
- Autoclave standard - 121°C (two atmospheres) for 20 minutes
- Steam must contact the organism to be effective
- Time and temperature vary inversely
- Moisture-sensitive items may be damaged
- Pulling a vacuum prior to steam introduction will reduce overall sterilizing time by quickly eliminating residual air

TABLE 6-14

Comparison of Moist and Dry Heat Resistance of Various Spores

Organism (as nominal levels of contamination)	Moist Heat Typical Destruction Time (min) of Bacterial Spores				Dry Heat Typical Destruction Time (min) of Bacterial Spores			
	100°C	105°C	121°C	135°C	120°C	130°C	150°C	160°C
Bacillus anthracis	5-10	5-10			45	20		
Bacillus subtilis	6-17						60	
Clostridium botulinum	330	120	4-10		120	60	25	25
Clostridium tetani	5-15	5-10				35	30	12
Soil bacilli	>660	420	6	0.5			180	30-90

Note: (1) Normal vegetative cells are usually killed by a temperature of 70°C (moist heat) in a 5- to 10-minute exposure.

(2) Bacillus stearothermophilus (spores) are more resistant to steam than to dry heat.

This type of information is subject to many variations, some of which are delineated in Paragraph 6.2.

Dry Heat

- Microorganisms more resistant to dry than moist heat

  Destroys organisms by "oxidation"
- Hot-air oven standard - 160°C for 2 hours (1 hour for penetration; 1 hour for sterilization)
- Time and temperature vary inversely
- Microbiocidal action markedly influenced by the nature of the medium, if any, surrounding the microorganism; i.e., film of oil or grease is protective
- NASA-recommended sterilization treatments (Table 6-15)
- Microbial spore resistance and variation (Table 6-14)

TABLE 6-15

Minimum Spacecraft Sterilization Time, Temperatures, and D-Values (Based on the Assumed "Worst Case" of 10^8 Viable Organisms)[a]

Temperature (°C)	D-Value[b] (hr)	Sterilization Time (hr)
160	0.21	3
155	0.31	4
150	0.46	6
145	0.73	9
140	1.1	14
135	1.8	22
130	2.8	34
125	4.4	53
120	7.0	84
115	11.0	132
110	17.5	210
105	28.0	336

[a]Sterilization procedures may change. Obtain the latest current requirements for a specific project.

[b]Based on thermal death-time curve of heterogeneous mesophilic bacterial spores in soil.

Source: Hall, Lawrence B., "NASA Requirements for the Sterilization of Spacecraft." Spacecraft Sterilization Technology, NASA SP-108 (1965).

b. Chemical -- Many materials do not lend themselves to sterilization by moist or dry heat because of their sensitivity to either the moisture or the increased temperature. Chemical sterilization by gases and vapors or liquids provides an attractive alternative.

(1) Gases and Vapors -- Generally, sterilization by means of gases and vapors involves the exposure of the material to a gas or vapor in an enclosed area at room temperature or slightly above. After treatment, the residual gas is removed by evacuation. The penetration is generally rapid into most materials, but it may be difficult to ensure that sterilizing conditions have been achieved throughout the total load being treated.

Antimicrobial gases (Table 6-16) are primarily patterned after ethylene oxide. For this reason, as well as the availability of information, this section will concern itself mainly with ethylene oxide.

TABLE 6-16

Properties and Applications of Commonly Used Gaseous Disinfectants

Disinfectant	Formula	Boiling Point (°C)	Flammability Limits in Air	Usual Concentration for Sterilizing Purposes	Relative Humidity (%)	Penetrating Ability	Microbicidal Properties	Use
Ethylene oxide	C_2H_4O	10.4	3.6 to 100 percent by volume; requires dilution by inert gases, CO_2, or chlorofluorohydrocarbons, for safe use.	400 to 1000 mg/l	25 to 50	Strong	Moderate	Most versatile gas for sterilizing purposes.
Propylene oxide	C_3H_6O	34.0	2.1 to 21.5 percent by volume; may or may not require dilution with inert gases for safe use.	800 to 2000 mg/l	25 to 50	Less than that of ethylene oxide.	Less than that of ethylene oxide.*	Frequently used as a substitute for ethylene oxide.
Formaldehyde	CH_2O	-21	7 to 73 percent by volume, but this hazard is minimized by the large percentage of water usually present.	3 to 10 mg/l	Over 75	Weak	Strong	Most commonly used as a surface sterilant.
Methyl bromide	CH_3Br	4.6	Essentially nonflammable.	About 3500 mg/l	40 to 70	Strong	Weak*	Usually employed as a decontaminant for fungi or vegetative bacteria.
Beta-propiolactone	$C_3H_4O_2$	163	No flammability hazard at room temperatures.	2 to 5 mg/l	Over 75	Weak	Very strong	Essentially a surface sterilant.

*Propylene oxide and methyl bromide are more commonly employed as gaseous decontaminants rather than sterilants; i.e., they are used to destroy specific groups of organisms such as fungi, yeasts, coliforms, and salmonellae.

Characteristics of Ethylene Oxide

Explosiveness	• Flammability limits in air: 3.6 to 100 percent, reduced by certain mixtures
Toxicity	• About the same as NH_4 gas • Liquid blisters skin • Maximum human tolerance: 100 ppm/8 hours
Penetration	• Rapid, difficult to determine thoroughness
Mixtures	• Mainly to reduce flammability • 10 to 12 percent ethylene oxide plus 80 to 90 percent carbon dioxide or chlorofluoro-hydrocarbons
Deterioration	• Degrades rubber (blisters), plastics (attacks plasticizers) • Is absorbed into rubber and plastics; considerable aeration time required • Ethylene oxide alone more deleterous than carbon dioxide-ethylene oxide mixture
Humidity	• Drastic reduction of effectiveness at very low relative humidity • Moisture required for sterilization: 40 to 50 percent RH
Temperature	• Normally used at 49° to 60°C • Sterilization at lower temperatures requires longer exposure • For each 17°C rise in temperature, the exposure period may be halved • Constant temperature eliminates condensation
Exposure time	• 3 to 24 hours, depending on penetration
Concentration	• Partial pressure of ethylene oxide in a closed chamber • Minimum: 400 milligrams per liter for exposure periods (6 to 16 hours) • Higher concentrations are more desirable; shorten exposure time, twice the concentration $\approx$ 1/2 exposure time
Mode of Action	• If sufficient ethylene oxide can get to the microorganism, in the presence of moisture, deactivation will result • Nonspecific alkylation of -OH, $-NH_2$, and -SH groups

Materials to be sterilized by ethylene oxide are usually packaged with some type of wrapping material to maintain sterility after the sterilization cycle. The following are guidelines for the selection of a wrapping material:

- Permeability to ethylene oxide and moisture
- Strength to withstand normal handling
- Low cost
- Flexibility
- Nondeteriorating in storage.

Plastic films, or the equivalent, 1 to 3 mils (0.001 to 0.003 inch) in thickness are preferred packaging materials. Examples of films used are shown in Table 6-17.

TABLE 6-17

Examples of Packaging Materials for Ethylene Oxide Sterilization

Film	Trade Name
Cellulose acetate plasticized	Lumarith P-912
Ethyl cellulose	Ethocel
Rubber hydrochloride	Pliofilm
Polyester	Mylar or Scotchpak
Polyethylene	Polyethylene
Polypropylene	Olefane
Polyvinyl chloride	Krene
2-mil nylon	RC AS-2400

(2) Liquids -- It is not within the scope of this handbook to effectively review the field of chemical disinfection. It is the purpose, however, to generalize and then give specific examples which serve to emphasize and undergird these generalizations.

"Disinfection is probably the operation most abused in the science of bacteriology, more so even than sterilization. The general impression seems to be that any type of disinfectant can be used in any amount, regardless of the situation to be dealt with, and the action is often assumed to be instantaneous."*

Inductive reasoning in this area requires thorough orientation in the field; i.e., the only factual conclusions to be drawn from a specific example are those pertaining directly to the conditions of the example.

Although a great variety of chemical compounds inactivate bacteria, very few are effective germicides. Finding a compound which is sporocidal and at the same time usable from a practical standpoint limits the choice of chemicals. An ideal germicide would be readily soluble in water, easily stored, inexpensive, fast acting, effective in solution or in vapor phase, volatile, nonresidual, readily inactivated, sporocidal, and not deteriorating to materials. Peracetic acid (CH_3CO_3H) and hydrogen peroxide come very close to this ideal but are highly corrosive to metals.

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*P. Sykes, "Disinfection - How, Why, When, and Where?" Journal of Applied Bacteriology 30(1), April 1967, p. 1.

The intrinsic activity of a chemical disinfectant is the first criterion of measurement. It enables a number of disinfectants to be compared one with another as to their relative activity or intensity of action. The conditions and types of microorganisms must be well defined in order to draw any comparison. One of the more common measurements of intrinsic activity is the phenol coefficient.

The phenol coefficient is a measurement of the activity of a disinfectant using the activity of phenol on a particular organism as a baseline. This is a suitable measurement when comparing phenol-like compounds but can be entirely misleading when comparing chemical compounds unrelated to phenol or when transposing from one organism to another.

Factors Affecting Disinfectant Activity	
pH	• Cell-disinfectant affinity may be disrupted by a pH change • Compound may be reduced in activity • Compounds may dissociate and become inactive; however, others may become more active
Organic matter	• Presence nearly always adversely affects activity • Competes with microorganisms for available compound, thereby reducing its availability • May react with, adsorb, or decompose a compound
Concentration exponent	• Characterization of disinfectants based on change in activity for a given change in concentration • Allows estimation of depression of activity when concentration or availability of a disinfectant is reduced by a known amount
Temperature coefficient	• Measurement of change in rate of disinfection per 10°C • change in temperature
Logarithmic order of death	• Disinfectant is acting on a population of microorganisms • Variation in the population--all cells do not die at the same instant • Death of a population of cells is a progression dependent on "several" parameters.
The above are parameters to be considered when evaluating disinfecting action. The particular situation governs the expression, exclusion, or effective intensity of these parameters.	

Mode of Action of Chemical Disinfectants	
Primary interaction of disinfectant/cell	• Absorption • Changes in electrophoretic mobility of the cell
Secondary interaction of disinfectant/cell	• Modification of cell permeability and leakage of cell constituents • General effects on metabolism • Irreversible, general coagulation of cytoplasm • Lysis

The action of chemical disinfectants is quite variable. When studying actions or interactions of cells and disinfectants, the property studied will be dependent on the concentration of the disinfectant. Some of these properties may be mobility in an electrical field, resistance, reproduction, and viability. A single index or property of a disinfectant is not sufficient to generalize about the disinfecting activity of the chemical under study. The index may give no more than an intuitive approach as to the practical application of a disinfectant.

It should be realized that microorganisms may develop resistance to a chemical or to a particular concentration of the chemical. The development of a resistance indicates a change or alteration in the metabolic pathways of the organism and these are usually hereditary changes or mutations, i.e., passed on to succeeding generations.

The spore forms of microorganisms (Figure 6-4) are more resistant to disinfectants than are vegetative forms. Their resistance is attributed to their anhydrous state and by a permeability barrier (spore wall) that must be breached for the disinfectant to act. Vegetative cells do not have the impervious walls around them. Relative to the spore, they have no permeability barrier; therefore, they are "easier" to inactivate than the spore.

The sporocidal effect of iodophors and organic and inorganic chlorine releasing compounds have recently been observed. Their effectiveness increases by the addition of bromine and an increase in pH. Tables 6-18 through 6-20 and Figures 6-9 and 6-10 serve as examples only, not generalizations, of the concentrations and activities of various germicides. Note the variation of spores of closely related organisms (Table 6-20).

TABLE 6-18

Liquid Decontaminants

Decontaminant	Normal Concentration Effective per Unit Time	Sporocidal Effect	Bactericidal Effect Vegetative Cells	Other Remarks
Phenolic compounds	1 to 5%/10 minutes	Effective at elevated temperatures on fungal and bacterial spores	Very effective	1. Examples: Vesphene, Staphine, Lysol, Cresol, Amphyl, Hexachlorophene 2. Not counteracted by organic matter
Alcohols (ethyl to amyl)	70 to 90%/10 minutes. Most action is in 1-2 minutes	Little or no effect on fungal or bacterial spores	Very effective	1. 70-percent volume aqueous solution best 2. Some water must be present for alcohol to exert effective action 3. Water miscibility limited-beyond propyl
Iodophors	10 to 25 ppm free iodine/1 minute	Have some effect at ordinary pH	Very effective, highly fungicidal	Neutralized by some organic and inorganic compounds. Examples: Wescodyne, Kleenodyne, Iopipe
Quaternary ammonium compounds	1 to 3%/10 minutes	Not effective	Not effective against some gram negative and acid fast organisms	Examples: Roccal, Zephiran, Emulsept
Chlorine compounds	4 to 1000 ppm/0.5-70 minutes	Effective at neutral or slightly acid pH	Not effective against acid fast organisms	May be more effective combined with other chemicals (Figure 6-9). Effect governed by formation of hypochlorous acid

TABLE 6-19

Sporocidal Properties of Some Halogen Compounds

Compound		Time (min.) to Kill 99% of B. cereus (spores) at 21°C	
		pH 6.5 Average halogen content, 50 ppm	pH 8.0 Average halogen content, 100 ppm
(NaOC1)	Sodium hypochlorite	3	5
(NaDCC)	Sodium dichloroisocyanurate	3	11
(DCDMH)	Dichlorodimethyl hydantoin	9	68
(DBDMH)	Dibromodimethyl hydantoin	27	25
	Iodophor	20	Not tested

Note: The above kill times cannot be extrapolated to sterility with assurance of accuracy.

Source: J. Appl. Bact. 30(1) (1967).

TABLE 6-20

Variation in Killing Time of Spores Representing Two Species of the Same Genus of Bacteria

Organism	Time (min) to Kill Spores with a Solution of:					
	NaOC1 (pH 8)	NaDCC (pH 8)	Iodophor (pH 2.3) - ppm Free Iodine			
	Ave. Cl 100 ppm	Ave. Cl 100 ppm	25	50	100	800
Bacillus cereus	5	11	53	20	12	--
Bacillus subtilis	60	105	≫240	≫240	≫240	≫240

Source: J. Appl. Bact. 30(1) (1967).

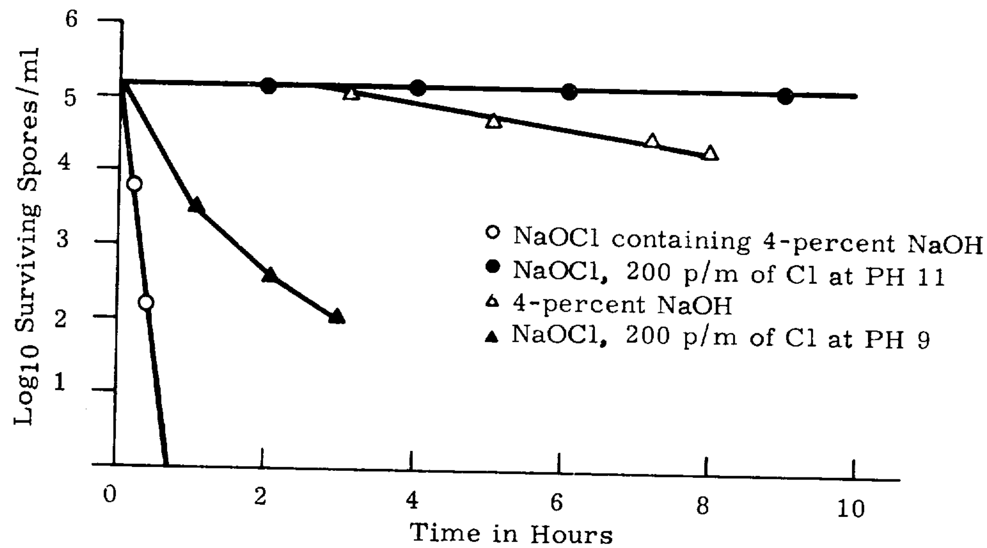
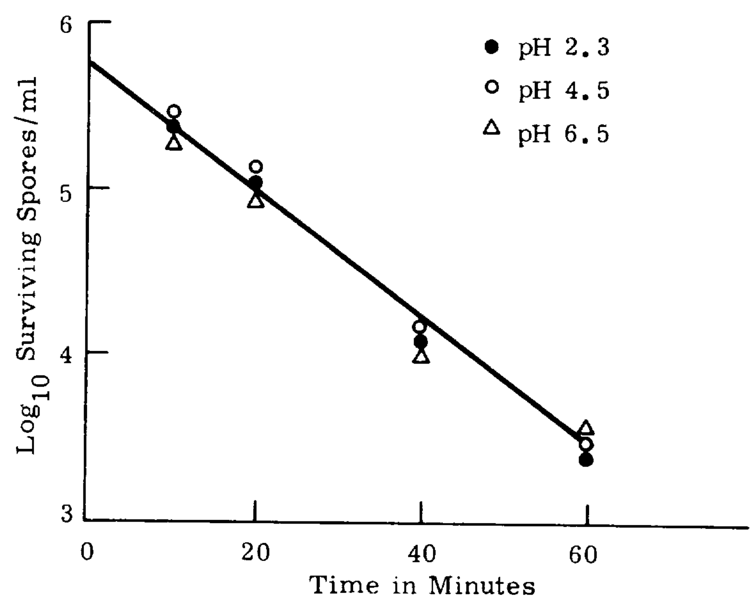


Figure 6-9. Deactivation time of Bacillus subtilus (spores) using NaOCl and NaOH



Influence of pH on the activity of an iodophor (25 iodine ppm) against spores of B. cereus at 21°C.

Figure 6-10. Influence of pH on the Action of Iodophor

The incorporation of a low concentration of a chemical germicidal agent into paints, plastics, greases, fuels, and electrical potting compounds can impart "self-sterilizing" properties to them. The effective method for making a solid material self-sterilizing is not obvious and must be developed empirically. Some chemicals which have been used are paraformaldehyde, beta-propiolactone, and salicylanilide. The sterilizing agents must be developed on the basis of desired properties of the materials as well as the spectrum of microorganisms to be destroyed.

c. Radiation -- Living matter contains many kinds of molecules that absorb radiant energy; this absorbency is an incidental consequence of their chemical structure. The first effect of radiant energy is to induce the intercepting molecules to an elevated state of energy which results in agitation or disruption depending on the energy input. This energy is dissipated within the mass and the distribution of it leads to changes in the cellular metabolism by a direct or an indirect means.

Radiant energy is carried in packets called quanta; the energy content of each quantum is identical for a given wavelength of light. The quantum energy changes with the wavelength; the longer the wavelength, the lower the quantum energy. Therefore, the effect on matter which a quantum can produce is a function of its wavelength.

Some definitions of terms used to define radiation doses are:

Roentgen (r)	• Fundamental unit in measurement of radiation doses • Number of ionizations produced per unit volume of air • Equivalent to an energy absorption of 83 ergs/gm of air • Equivalent to an energy absorption of 93 ergs/gm of water
Rad	• Energy absorption of 100 ergs/gm of material
REP	• Roentgen - equivalent - physical • Energy absorption of 100 ergs/gm of living tissue

For practical purposes each of these units can be taken as equivalents; the error introduced by interchange is comparatively small.

Figure 6-11 and Table 6-21 give an overview of the effects of various types of radiation on bacteria and fungi. The spore, as can be observed from the table, is more resistant to radiation than the vegetative cell. Speaking very generally, microorganisms with a thick cell wall or those having pigments are "more" resistant to radiation. It should be noted (Table 6-21) that within the same genus of microorganism there is variation in radiation sensitivity.

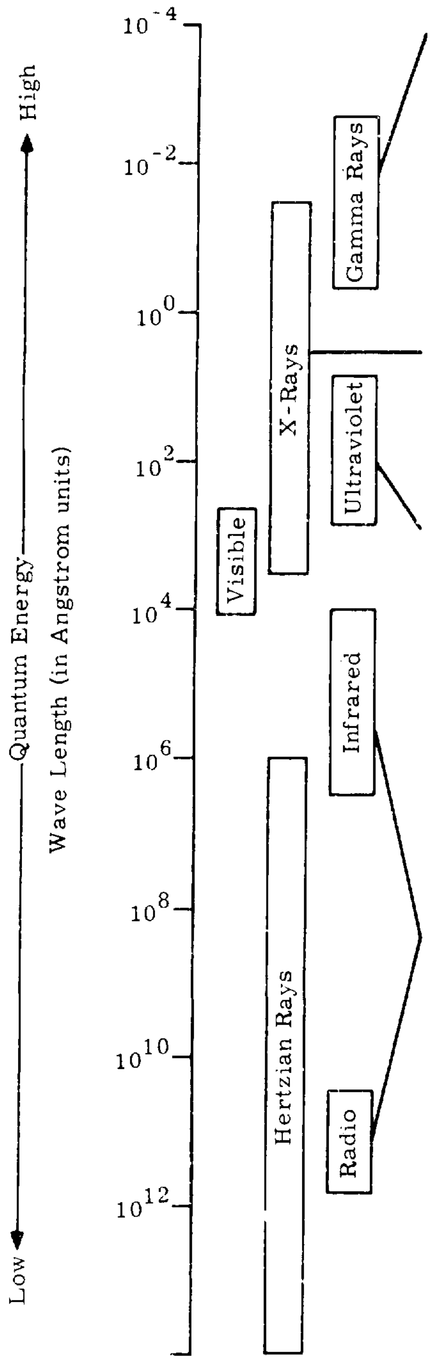
TABLE 6-21

Effect of Radiation on Bacteria and Fungi

Organism	Stage	Dose		
		UV 2 537Å 90% Inhibition erg/cm^2 x 10^2	γ-Rays 100% Inhibition rad x 10^6	X-Rays 90% Inhibition r x 10^3
Bacillus anthracis	Spores (Figure 6-4)	452		
Bacillus megaterium	Spores	273		291
Bacillus megaterium	Vegetative (Figure 6-4)	113		
Bacillus subtilis	Spores	900		
Bacillus subtilis	Vegetative	520		
Aspergillus niger	Conidia	23,000	0.32	
Bacillus brevis	Spores			47
Bacillus cereus	Vegetative		0.075-0.15	27
Escherichia coli	Vegetative		2.1	
Bacillus pumilus	Spores,		0.9	
Saccharomyces cerevisiae	Vegetative			

Most cells, spores excepted, consist of 70 to 90 percent water by weight. For this reason, cells are assumed to be equivalent to water for purposes of radiological calculations.

Ionizing radiations in X-rays and gamma rays lose part of their energy when they pass through water thereby causing water molecules to ionize. The important products formed are the OH^- and the H^+ ions. The OH^- is a strong oxidizing agent and the H^+ a strong reducing agent. The fundamental effect of ionizing radiations on solutions is to produce free radicals having either an oxidation or a reduction potential; the action or reaction of these free radicals then causes the damaging effect. This dissipation of free radicals by the cell is a rather slow process. Heat and certain gases are thought to increase the dissipation. Free radicals are made irreversibly toxic to the cells by their reaction with oxygen, and it is this aspect that makes the presence and concentration of oxygen very important in radiation decontamination or sterilization. The significant range of oxygen concentration lies between 1 to 10 mg/liter. The presence of oxygen enhances decontamination by radiation.



<u>Gamma Rays</u>

- High energy - emitted from radioactive isotopes
- Spores more resistant than vegetative cells
- Mode of action
  - Direct - functional destruction of proteins and/or nucleic acids
  - Indirect - free radical formation
- Greater penetrating ability than X-rays

<u>X-Rays</u>

- Difficult to direct
- Considerable penetrating ability
- Spores more resistant than vegetative cells
- Mode of action - same as gamma

<u>Ultraviolet</u>

- 2650 Å - highest bactericidal efficiency
- Very little penetrating power
- Air or surface sterilization
- Mode of action - direct - on DNA-forming thiamine dimer
- May be mutagenic
- Spores more resistant than vegetative cells
- Photoreactivation - lethal and mutagenic effects are not entirely irreversible

<u>Infrared-Radio</u>

- Bactericidal effect - by means of heat produced in the absorbing mass

Figure 6-11. Electromagnetic radiation and bactericidal action

6.2.2 Removal

Filtration is generally employed to remove microorganisms when liquids, solutions and, in few instances, gases are thermolabile; i.e., destroyed or inactivated by heat.

The filtration material varies with the type of filter, i.e., asbestos pad, diatomaceous earth, porcelain, sintered glass, membrane or molecular filter for liquids, and membrane filter, cotton plug or other fibrous materials for gases. These filters do not act entirely as mechanical sieves, since other factors beside pore size, such as diffusion, electrical attraction, chemical affinity, etc., affect the removal of microorganisms from their environment.

The mean pore size of these bacteriological filters ranges from one to several microns. Most filters are available in several grades. Various characteristics of filter materials are delineated in Table 6-22.

TABLE 6-22

Efficiency and Flow Resistance Range of Devices for Removing Biological Particles (1-5 μ) from Air

Filter Type	Media	Resistance at Rated Capacity (in H_2O)	Bacterial Removal (%) (1-5 μ)
Roughing	Usually composed of materials such as loosely packed fibers of animal hair, synthetic fibers, or woven metal screens	0.04 to 0.10	10 to 60
Medium efficiency	Compressed glass, asbestos, cellulose, or other types of fibrous media	0.09 to 4.0	60 to 90
High efficiency	Chiefly glass fibers, a good grade of fiber paper, or asbestos fibers, with the diameter of the fiber usually ranging from 1 to 5 μ	0.2 to 0.50	90 to 99
Ultrahigh efficiency, currently classified as high-efficiency particulate air (HEPA)	Generally constructed of fire-resistive glass or glass-bearing media	0.9 to 1.0	99.99+
Complete filtration	Special glass microfiber web with a mean fiber diameter of 0.1 μ	13.6	99.999999+

Source: H. M. Decker and L. M. Buchanan, Filter Applications for Spacecraft Sterilization Program, Spacecraft Sterilization Technology, NASA SP-108 (1965).

6.2.3 Isolation

The idealized approach to microbial control is to exclude microbial contamination; this eliminates problems of inactivation, decontamination, and the like. Obviously, exclusion is frequently an impossibility. The ubiquity, size, and diversity of microorganisms are some of the dynamic variables which make this unfeasible. However, any method for reducing the total numbers of microbes in a particular area is an effort in the right direction.

The three basic subdivisions of isolation are:

a. Placing a sterilized mass within a biobarrier, sterilizing it, and storing it until ready for use; in this instance, isolation is maintained by wrapping the mass or placing it in a container, isolating it from and disregarding the ambient environment. The probability of sterility will be no better than the unwrapping technique and the contamination level of the area in which unwrapping takes place.

b. Rendering the immediate ambient environment "particle free" by air filtration. The filtered air is contained in a room, hood, etc., and may also be directed (laminar flow).

c. With gradient air pressures, one area is isolated from another by a difference in air pressures.

Table 6-23 exemplifies and further explains the methods of isolation. Table 6-24 evaluates various plastic films.

TABLE 6-23

Methods of Isolation

Method	General Purpose	Examples	Remarks
Biobarriers	Storage of material	Petri dishes White suits Plastic films Other wrapping material	Storage of sterile media Contains contamination Sterile piece part storage Sterile storage
Filtration	Isolate one environment from another	Filtered air clean rooms Filtered air, laminar flow rooms or hoods	Used to produce large volumes of particle-free air Produces work area with a low level (dependent on personnel activity) of microorganisms
Gradient air pressures	Isolate one environment from another	Positive pressure areas Negative pressure areas (exhaust hoods, exhaust suits)	Excludes ingress of particles Contains and removes particles

6.3 Monitoring Methods for Microbial Contamination

Methods of monitoring microbial contamination may properly be separated into appropriate methods for the different categories of substances being monitored. Normally these categories would include air and gases, liquids, solids, and surfaces of solids. In addition, it may be advantageous to consider people and the food they consume as separate categories.

TABLE 6-24

Evaluation of Bagging Material as Bio-Barriers

Material Description	Results	Comments
Nylon, 2-mil RC AS-2400	Satisfactory	Heat sterilizable; best results with double bag technique due to thin film (2 mil)
Clear polyethelene, 2 mil	Unsatisfactory	ETO* sterilizable; too sensitive to tearing, creasing, and cutting
Clear polyethelene, 7 mil	Unsatisfactory	Heat-sealed seams brittle and porous-leak often
Clear PVC, 12 mil	Satisfactory	ETO sterilizable, resists tearing; heat seals do not leak
Sealing tape Scotch brand pressure-sensitive Type 470	Satisfactory	ETO sterilizable. Resistant to peracetic acid. Seals appear to be leak free. Resistant to total immersion in peracetic acid after 30 days.

*Ethylene oxide.

Source: Prepared by McDonnell-Douglas Corporation, St. Louis, Missouri.

Current technology in the monitoring of viable aerosols is limited from dirty to moderately clean environments. Commercial instruments are yet to be developed which adequately sample extremely small numbers of organisms, and this limitation should be recognized when reading the following discussion.

6.3.1 Air and Gases

Methods of sampling microbiological aerosols may be divided into three types:

a. Impingement in a liquid

b. Impingement on a solid surface

c. Filtration.

While a number of liquid impingement devices exist for monitoring viable aerosols, the all-glass impinger (AGI) is the one most often used, and indeed has been recommended as one of the standard instruments to which other devices may be compared.*

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*Science 144:1295.

The AGI operates at near sonic velocity and has a flow rate of 6 or 12.5 liters of air per minute. Organisms are impinged in the liquid of the AGI and must later be diluted and plated in order to determine the number of organisms present. The shearing action of the high flow rate results in breaking up clumps of organisms to a degree, so that the total number of viable organisms is obtained rather than particulate aggregates. This activity of the high flow rate also will destroy many organisms unless they are protected by an appropriate collection fluid. This sampler is useful only for collecting aerosols which are fairly heavily laden with viable particles.

Three solid impaction techniques have found wide utilization in the collection of aerosols. The settling plate is the oldest and simplest of the techniques. It is the least expensive of all sampling methods, but its disadvantages include the fact that no measure of the quantity of air sampled is possible and also only the larger particles may be sampled.

The Andersen sampler is highly efficient for the collection of particles 1 to 10 microns in diameter and it discriminates collected particles into six different size ranges. No diluting or plating procedures are required, but the sampler is not suited for the collection of high concentrations of organisms for long-term operation. The six-stage Andersen sampler has also been recommended as one of the standard samplers to which other devices may be compared.*

The Reynier slit sampler has a time-concentration relationship with the particles being impacted onto the agar surface of a rotating dish timed by a clock motor. Here also, no diluting or plating procedures are required and the sampler is not suited for the collection of high concentrations of organisms.

The membrane filter is the most common technique for monitoring viable aerosols by the filtration method. Membrane filters may be obtained with pore sizes down to 0.01 μ or smaller and with airflow rates from 0.3 to 55 liters/min/cm^2 depending on pore size. Viable bacterial particles may be cultured directly on the surface of the filters (usually 0.22 or 0.45 μ pore size) using appropriate techniques, or they may be overlayed with a nutrient agar medium and incubated for growth of organisms. No plating or diluting procedures are necessary, but the technique is inappropriate for the collection of high concentrations of organisms. In addition, this technique, as well as other air filtration methods, is suited for the assay of only those organisms which are resistant to drying.

Two other filters used for the collection of submicron particles are the Chemical Corps filter of Type 6 filter paper which is composed of cellulose and asbestos fibers, and the Mine Safety Applicances 1106BH glass filter paper.** After the collection of viable particles on the filters they are placed in broth, shaken on a mechanical shaker, and the broth plated. This technique results in the biological decay of some organisms.

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*Science 144: 1295.

**J. B. Harstad, "Sampling Submicron T_1 Bacterophage Aerosols," Appl. Microbial. 13 (1965), pp. 899-908.

6.3.2 Liquids

Liquids may be monitored for viable contaminants in two ways. First, they can be passed through membrane filters and then the filters subjected to appropriate techniques to culture the organisms. Membrane filters can be obtained in pore sizes from 0.01 to 10 μ or more with flow rates of from 0.5 to 100 $ml/min/cm^2$ depending on pore size.

Secondly, liquids may be subjected to aliquot sampling and the samples tested for viable contamination. Statistical analyses can be made by the most probable number (MPN) technique* to determine estimates of microbiological loading. This technique is less accurate than the use of membrane filters.

6.3.3 Solids

No techniques are presently available which are suitable for the assay of viable microorganisms present internally in solids. Suggested techniques to date utilize pulverization, fragmentation, shavings, etc. All generate enough heat so that a certain percentage of viable organisms present are likely to be destroyed by the assay procedure. The chemicals employed to dissolve the solids can also be inhibitory to microorganisms.

6.3.4 Surfaces

The swab-rinse method may be employed to assay surfaces; however, residual rinse fluid is left on the area sampled. The scrubbing action of the swab and the liquid solubility action are the only forces of removal. The area sampled is usually small, thus requiring tedious extrapolation. Results are usually quite variable due to variable efficiency of removal.

Rodac plates may only be used for sampling smooth, flat surfaces. The sampling area is small again, thereby requiring tedious extrapolation which gives variable results. Small residuals of nutrients are also left on surfaces. The removal efficiency is generally less than 70 percent.

The vacuum probe sampler, a recent development by Sandia Corporation, holds great promise in the area of surface sampling. The technique employs the removal of particles, including microbes, with a vacuum and collects them on a membrane filter from which they can be subsequently assayed. The efficiency of removal is greater than 90 percent and the area sampled may be very large. This sampling device is restricted in that it must be used in clean air, Class 100 or better clean rooms, to totally eliminate background noise.

The more pertinent methods of monitoring are outlined in Table 6-25.

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*Standard Methods for the Examination of Water and Sewage, 12 ed. Amer. Pub. Health Association.

TABLE 6-25

Techniques for Microbial Monitoring

Item to be Sampled	Equipment or Technique	Resulting Data
Airborne contaminants	Andersen sieve sampler Reyniers slit sampler AGI Membrane filter	Organisms per volume
Microbial fallout	Stainless-steel settling strips Agar settling plates	Organisms per area per time
External surfaces general	Vacuum probe Rodac plates Cotton swab rinse	Organisms per area
Small parts	Immersion rinse	Total organisms
Clothing	Rodac plates Garment monitor Immersion rinse	Organisms per area Total organisms
Skin surfaces	Tape	Organisms per area
Interiors of components and materials	Diamond drill Ball mill	Total organisms or Organisms per volume

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SECTION 7

RADIATION

Radiation is energy having characteristics of wave motion or particle motion. The energy in a wave is a function of the amplitude, and velocity which is a product of frequency and wavelength. The energy of a particle is a function of the mass and velocity of the particle.

Wave energy may be of mechanical origin such as vibration or sound, or electromagnetic such as radio waves and light. Particle energy may be of atomic or subatomic origin by either natural or induced transformations.

For the purpose of this handbook, these energy forms are categorized as electromagnetic, mechanical, and particle radiation.

7.1 Radiation as a Contaminant

Contaminating radiation is the radiant energy in, on, or around the contaminee. Radiation can change the state of a material, induce a chemical reaction, change a physical characteristic, or alter an electrical or magnetic characteristic. Examples of some of the effects of contaminating radiation commonly encountered are radio and electrical interference, contaminated photographic film, human discomfort and tissue damage, and physical damage to structures.

The major categories, with the various types of radiation for each, along with some of their contaminating effects are:

Radiation	Effects
Electromagnetic Radio waves Infrared Visible light Ultraviolet X-ray Gamma ray	Heat, photochemical, electrical interference
Mechanical Subsonic Audible sound Ultrasonic	Heat, stress, strain, structural modification

Radiation	Effects
Particle Alpha Beta Neutron	Heat, modification of basic structure of material (mechanical or chemical)

7.2 Control of Radiation Contamination

The methods available for controlling radiation contamination consist of eliminating the radiation source, reducing the intensity of the energy emitted from the source, and shielding the contaminee from the radiant energy, or some combination of the three. The techniques required to control this type of contamination may be quite complex.

Eliminating or reducing the radiation source is limited to those situations in which control of the source can be exercised by some practical means. Shielding involves the use of some type of barrier between the source and the contaminee that will suppress, absorb, reflect, or refract the transmission of radiant energy.

Common barriers and the form of energy they control are shown below:

Energy	Barrier
Heat	Thermal insulation, cooling devices, reflective coverings
Sound	Acoustic absorptive materials, frequency filters
Light	Opaque materials
Vibration	Isolation mountings, vibration dampeners, resilient vibration absorptive materials
Radioactivity	Lead (gamma and X-rays), water, plastic (neutrons), most materials (alpha and beta).

7.3 Radiation Monitoring

The methods for monitoring radiation contamination are generally selective and specialized in their application. Some of the more commonly applied monitoring methods are listed below and accompany the radiation form for which they are suited:

a. Light, X-ray, Infrared:

(1) Film -- Changes upon exposure to light. Effectively integrates intensity and time of exposure. Film may be color-sensitized to specific light wavelengths, or light-filtered for specific wavelengths.

(2) Photoelectric cells -- Photoemissive elements of alkali metal oxides (such as sodium, potassium, cesium) are sensitive from deep ultraviolet to infrared. Photoconductive cells such as those utilizing lead sulfide respond to radiation with wavelengths to about 3 microns.

(3) Bolometer -- Radiation raises temperature, thereby increasing resistance which is used as a measure of radiation.

b. Particles (Alpha Particles, Electrons, etc.):

(1) Proportional counter -- A gas-filled tube in which particles with sufficient energy to ionize gas cause electron flow with each ionization. Current pulses are fed to pulse amplifier and counters. Neutrons require tubes filled with different gases than are required for charged particles (H_2 for fast neutrons, BF_3 for slow ones). Photons (gamma rays) cause electrons to be emitted from metallic wall of counter, thereby creating gas ionization.

(2) Geiger counter -- Similar to proportional counter, except higher voltage is used. Single ion pair produced by one particle can be detected. Large constant output pulse requires simple associated circuits. Geiger counter gives no information concerning energy of particle.

(3) Scintillation counter -- Particle or photon produces internal secondary electrons in luminescent crystal or plastic (photocathode of photomultiplier tube).

(4) Semiconductor -- Electron-hole pairs created by particles (in p-n junction beneath surface) cause current to flow.

(5) Dosimeter -- Deflection of charged plates change with loss of charge due to ionization, indicating integrated radiation.

c. Sound and Vibration:

(1) Microphone -- Sound pressure deflects a diaphragm which either exerts a force on a crystal to generate an electrical voltage, or moves a coil in a magnetic field to generate a voltage. Both frequency and amplitude of the sound can be measured with microphone and associated equipment. Microphones are used in air or gases.

(2) Transducers (accelerometers) -- Crystal (barium titanate or similar crystal) is deformed by inertia of a mass undergoing acceleration during vibration. The deformation creates an electrical voltage across the crystal.

(3) Visual -- Gage measurement of the displacement of the object being vibrated. Acceleration can be computed after determining displacement if the frequency of vibration is known.

(4) Velocity pickup -- A mass with a coil attached to it is accelerated through a magnetic field, inducing a voltage in the coil proportional to the velocity of the relative motion between coil and magnetic field. This method is best for low frequencies (above about 10 cps).

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SECTION 8

CLEAN PACKAGING

Prior to World War II, the principal objective of packaging was to protect the contents of the package from physical damage and general environmental conditions. However, the handling and storage problems encountered during World War II emphasized the need for a more scientific approach and the necessity for greater protection capabilities. As a result, significant developments were made in cushioning, desiccants, marking inks, moisture-vapor barriers, and packaging technology.

The advent of precision, microminiature, and high reliability components provided the impetus for developing "clean packaging" materials and techniques. Concurrently, the other essential ingredient for clean packaging--clean working environments--was developed.

Packaging in general constitutes enclosing an item in some material to protect it from some environmental condition. Clean packaging is more definitive in that it protects critical areas from specific contaminants or contaminating environments and requires individual analysis of each packaging situation. It may involve sealing ports or openings into a specific area or enclosing an entire assembly. It may include items ranging from microminiature parts and components to complete assemblies and systems.

The theory of clean packaging is simple: the package must be capable of maintaining the cleanliness requirements of the packaged item, and this condition must be maintained throughout handling, storage, and transportation until further assembly or use. In order to achieve this end, the following conditions must exist:

a. The packaging material must be cleanable and precision-cleaned prior to use.

b. The cleanliness level of the cleaned packaging material must be maintained from the point of cleaning until a closure is effected.

c. The packaging operation must be accomplished in a clean environment.

d. Stringent clean packaging techniques must be observed.

e. The package must be constructed and sealed so as to prevent the entrance of contaminants from outside the package.

f. The packaging material itself must not contribute contamination, except within controlled and acceptable limits.

In many fields of endeavor, a great emphasis is placed on achieving a specified cleanliness level. Unless this cleanliness level is maintained, usually through clean packaging, the clean effort is substantially nullified.

8.1 Preparation for Clean Packaging

Many factors in addition to packaging materials and methods must be considered if the desired result is to be achieved. If clean packaging requirements are critical, it is preferable that a specification be prepared for each item or entity to be so packaged. However, due to the large number of parts or assemblies involved in some programs, it may be more practical to establish some system of classes or methods into which most of the items can be conveniently categorized. The determination of the type of grouping adopted will depend on conditions such as the following:

a. The degree of cleanliness required

b. The material composition of the item being packaged

c. The configuration of the item being packaged

d. The intended use of the item, including other materials with which it will be in contact, criticality of the operation, etc.

e. The extent and type of handling, storage, or transport anticipated prior to use.

These and other points are discussed in the following paragraphs.

8.1.1 Determination of Cleanliness Levels

In determining the cleanliness level to be maintained by clean packaging, primary consideration should be given to the item or class into which the item belongs and its functional cleanliness requirements. Other considerations are the availability of environmentally controlled areas and the degree to which the packaging materials are cleanable, resistant to sloughing of particles, and capable of excluding adverse environmental conditions.

The cleanliness level requirement, along with the degree of handling and transport involved, may also have a distinct bearing on the type and amount of cushioning and packing materials used to protect the contents of the clean package.

It is common practice to establish cleanliness levels for an entire functional system when extensive and complex projects are involved. Each contractor contributing to such a project often establishes his own standards of cleanliness to meet the system requirements. This method of operation, though usually satisfactory, is less preferable than a full coordinated establishment of cleanliness levels among the various contractors. The latter method would probably reduce conflicts, recleaning and repackaging, and additional costs in subsequent assembly, inspection, and testing operations.

8.1.2 Preparing the Item to be Packaged

Detailed information on parts cleaning methods, cleaning agents, and soils are contained in Section 3 of this handbook. It should be sufficient to point out here that any item to be clean-packaged must be properly cleaned and dried prior to packaging, and that its clean condition must be maintained until a clean packaging closure or enclosure is effected.

Particular attention should be given to the removal of moisture and cleaning agents from the components prior to clean packaging. This can usually be accomplished by the application of heat, vacuum, a dry purge gas, or some suitable combination of these methods.

8.1.3 Selecting or Preparing the Packaging Material

The availability of packaging materials which can meet the requirements for clean packaging is limited by three conditions: (a) the material must be cleanable to the degree needed, (b) the material must exhibit a low particle sloughing tendency, and (c) it must possess the capability for effecting a hermetic seal in a manner that will not contribute to contamination of the package.

Packaging materials which have found wide application are plastic films such as polyethylene, polyamide (nylon), and fluorohalocarbon (Aclar). These films may not possess all of the required characteristics to the degree desired; however, they are adequate for many applications. The characteristics of these films are described in detail in Paragraph 8.2, but their attributes for clean packaging are generally considered to be:

Polyethylene - moisture vapor barrier; medium sloughing

Nylon - minimal sloughing; flex-resistant

Aclar - moisture vapor barrier; particles are LOX-compatible.

Packaging films are not manufactured in a clean condition, but clean films are available from several convertors and clean product suppliers throughout the country. Clean film can be procured in various forms such as roll stock, bags, shrouds, and tubing.

Small sections of film, including bags, may be effectively cleaned by the user who has adequate cleaning and drying equipment. Precision grade trichlorotrifluoroethane is the cleaning agent normally used for film cleaning. Cleaning film on a large scale, however, requires rather elaborate, mechanized cleaning equipment and a clean room in which further packaging of the clean film is accomplished. In no case can the clean film be exposed to ambient factory environmental conditions after it leaves the cleaning equipment. Therefore, the cleaning equipment must be located in the clean room, which in most cases is not advisable, or the clean film must issue directly from the cleaning equipment into the clean room through an appropriately protected pass-through. The type of installation described above would be economically feasible only for the very large user or commercial convertor of clean film.

8.1.4 Packaging Facilities, Equipment, and Personnel

In order to accomplish its objectives, all clean packaging operations must be carried on in an environmentally controlled area which provides an adequate degree of protection for both the item and the clean packaging material. The degree of protection needed should be consistent with the product cleanliness requirements, and may range from a Class 100 (Fed. Std. 209a) clean room to a nonlaminar airflow clean room with some lesser degree of particulate and environmental control. Any preparation of clean packaging material, i.e., unpacking from original container, cutting, trimming, initial heat sealing, etc., should be done in the exhaust or downstream portion of the clean room. Items connected with these operations should be brought into the immediate vicinity of the clean parts only during actual use.

All necessary equipment and supplies for clean packaging must be as clean as possible, in good operating condition, and readily accessible for use. All cutting devices must be well maintained in a sharp condition to minimize particle generation and ragged material edges.

As in any contamination control activity, people are a most important ingredient to successful clean packaging. Anyone being introduced to a clean packaging operation should receive, as a minimum, some degree of formal and on-the-job training in the following essential aspects of his job:

a. The philosophy of contamination control

b. The specific need for clean packaging

c. The proper operation of equipment and use of materials

d. The specification requirements of the product

e. The regulations governing attire and conduct in an environmentally controlled area.

Personnel should be selected for this function on the basis of both their mechanical aptitude and their understanding and willingness to conform to established practices and regulations.

The proper utilization of personnel in clean packaging, however, is not solely dependent on training. Competent supervision is equally important.

Additional information on personnel and training may be found in Section 10.

8.2 Packaging Materials

The adequacy of any material to protect an item from being contaminated is dependent on the cleanliness level that must be maintained. This can cover an extremely wide range of levels. To better relate material performance criteria to required cleanliness levels, the principal qualities that a material should possess are categorized as follows:

a. Barrier to External Environments -- A good barrier should be capable of excluding those contaminants in the external environments which would cause contamination of the packaged item.

b. Minimum Contributor of Contamination -- An ideal material would not in itself contaminate the packaged item or adjacent environment by release of particles from sloughing or contact-abrasion or from emission of vapors.

c. Compatible for Use in Hazardous Environments -- A material which would not contribute to an explosive, flammable, or corrosive condition when exposed to environments containing concentrations of oxygen and explosive mixtures, volatile vapors, hypergolic propellants, and other flammable substances.

The properties and characteristics of materials as related to the above principal qualities are discussed in Paragraph 8.2.3.

An evaluation of any group of materials to meet the requirements for a specific application of clean packaging may reveal that no one material possesses all of the required qualities and characteristics. This is especially true as the required cleanliness level becomes more stringent.

The preservation of a precision-cleaned item by a packaging technique may require materials and methods which are currently not available, unknown or untried. Situations of this nature call on the ingenuity of the personnel involved to develop the techniques that will enable them to meet the requirements.

The following paragraphs discuss the types and characteristics of the packaging materials currently available and commonly used, with current information on significant limitations and qualities for clean packaging.

8.2.1 Barrier Materials

Materials used in the clean package as a barrier to contaminating environments may be categorized in several ways. For simplicity and practicality, these materials are grouped herein according to structural type and to package application.

a. Structural Type -- These groups consist of the following:

(1) Rigid -- This group includes metals, glass, ceramic, and rigid plastics which are cleanable to the degree required, provide adequate environmental protection, and are minimal contributors of contaminants. They may be used as intimate and environmental packages.

(2) Nonrigid or Flexible -- This group consists principally of metal foil and plastic films which are cleanable to some degree. The barrier qualities will vary with different materials. The sloughing of particles due to abrasion and flexing is prominent in all materials of this type, especially

in those of lower density. These may be used as intimate and environmental packages and as intimate cushioning material.

b. Package Application -- The three basic elements or parts which make up a complete clean package are as follows:

(1) Intimate Package -- The material used for this part of the clean package requires the same degree of cleanliness as the clean item. The material may contact the clean surfaces or is environmentally adjacent to those surfaces. It should be capable of providing a hermetic seal to external contaminants and environments.

The rigid materials of high density and hard finish can provide the highest degree of cleanliness and effective barrier qualities. Some impediments to the use of rigid materials may be in forming to a particular configuration, sealing, and securing the item within the enclosure to prevent damage to the item and container and still maintain the required cleanliness.

Nonrigid or flexible materials are limited in the degree of cleanliness they can maintain due to their sloughing characteristics. Metal foils are cleanable to a good degree, but flexing and abrasion will create considerable particle generation. Plastic films of high density and smooth surface finish are readily cleanable, and they generate fewer particles than the low-density films. Many of the plastic films are heat-sealable and are effective barriers to certain environments.

(2) Environmental Package -- This part of the clean package is used to provide an additional barrier to specific environments which may not be provided by the intimate package material, and to provide the intimate package with protection from the various environments encountered during handling operations and storage.

The sloughing characteristics of flexible film material used for this package may be of less significance, and emphasis can be placed on those characteristics that provide the best environmental barrier. Many of the plastic films are effective barriers to moisture vapor, oils, greases, other gases and liquids, and are heat-sealable.

The rigid materials possess all the barrier qualities of the films and, in addition, provide greater physical protection from forces both within and outside the container.

(3) Intimate Cushioning -- Clean items which have sharp edges, protrusions, or external threaded portions may require some form of cushioning to protect the intimate and environmental package from puncture or damage. The material used for this part of the package requires the same degree of cleanliness as the item because of its intimate contact with the item. Where a plastic film is used as the intimate package, the same material is commonly used for cushioning by placing a number of layers over the areas required.

8.2.2 Ancillary Materials and Accessories for Clean Packaging

In addition to the basic materials for closures, enclosures, and cushioning of a clean package, certain other materials are necessary to form a complete clean package. Most of these items and material will be used in the clean packaging operation either internal to the package or adjacent thereto. Therefore, the cleanliness of the items and the handling procedures must be compatible with the cleanliness level of the clean packaging operation. The following items are commonly used in clean packaging operations; however, special situations may require additional items which should be given the same considerations for cleanliness.

a. Tape, Adhesive-Backed -- May be used in some instances for securing cushioning material to the item, sealing closures or wraps, and securing other items to the package. The tape material and the adhesive should not generate contaminants or degrade the package material.

b. Ribbons and Ties (Nonadhesive) -- May be used for the same purposes as the adhesive-backed tape and may be preferred to eliminate the possibility of contamination from the adhesive. Material of this type should be cleanable and nonshedding to the degree required.

c. Identification Labels and Tags -- Normally required for proper and complete identification of the clean package and item contained therein. They should be preprinted to preclude the need for marking materials in the clean packaging area. Labels, tags, and markings thereon should be of materials which are nonfading and minimal in generation of contaminants.

d. Desiccants and Humidity Indicators -- When static dehumidification is required in the clean package, desiccants may be used with provisions to ensure that the clean item is not contaminated by desiccant dust or the desiccant bag material. Desiccants contained in bags which are impermeable to desiccant dust and noncorrosive are available. Similar measures should be taken to protect the clean item from contamination by humidity indicators, when used.

e. Purging Gases -- Inert gases such as dry nitrogen used for purging the clean package prior to sealing the closure shall be of a purity equal to or better than the cleanliness level of the item. The impurities to be considered include water vapor, hydrocarbons, and particles that would contaminate the clean item. Filtration of the gas shall be adequate to ensure removal of all contaminating particulates.

f. Integrity Seals -- Tamperproof-type seals or decals may be used to detect violation of the integrity of a sealed clean package or closure. These items shall be of such material and configuration that their application does not result in deterioration or violation of the closure.

g. Intermediate Package Materials -- Items of a fragile nature should be provided physical protection after being clean-packaged and prior to extensive handling. Materials used for this purpose include cushioning, compartmentalized containers, environmental barrier covers or wraps, etc. Materials of this type should be applied outside the clean packaging area.

8.2.3 Characteristics and Properties

Packaging materials have certain characteristics and properties which are significant to clean packaging. The characteristics as related to the requirements of clean packaging are described in the following paragraphs.

a. Strength -- Should be adequately resistant to penetration by tearing, parting or piercing from forces either external or internal during normal handling operations. Rigid materials provide the greatest strength. The flexible foils and films are more susceptible to damage.

b. Permeability -- Should have a low degree of permeability to the gases, vapors, and liquids which may be encountered. Some rigid materials and high density plastic films are essentially impermeable and have a low water-vapor-transmission-rate (W-V-T-R).

c. Formability -- The capability of forming to a desired shape or configuration. The flexible foils and films are the most easily formed. The rigid materials require more extensive preforming or molding operations.

d. Resistance to Oil and Grease -- The resistivity to reaction when in contact with oils, grease, and other petroleum products which result in deterioration and penetration of the material. Metals and metal foils may be the most resistive with some of the plastic films having a high degree of resistance.

e. Temperature Range -- The range of temperatures within which the material does not deteriorate or degrade as a barrier. Includes the tendency of some films to block or stick together or stick to the packaged item. Metals and metal foils provide the greatest usable temperature range. The low density plastic films block at relatively low temperatures, which may be a limiting factor for some applications.

f. Sealability -- The capability of sealing the material to itself or other material to form a hermetic closure. The method of sealing should not contribute contamination to the interior of the closure. Rigid materials and metal foils may require compressive or adhesive materials, which may not be applicable in some instances. Heat sealing is the simplest and most common method of joining plastic films. The major techniques commonly used are thermal, dielectric, and ultrasonic. Many of the films can be sealed by more than one method, and essentially all of the films can be sealed effectively by at least one of these methods. For more information on the sealing methods see Paragraph 8.3.4.

g. Transparency -- A transparent material may be desirable in some instances to facilitate identification and inspection of the packaged item. Other situations may require the exclusion of light necessitating the use of opaque materials. Many of the plastic films are naturally highly transparent although others are pigmented to aid in their identification. The metals and metal foils are the most opaque.

h. Cleanability -- The material should be capable of being cleaned to the the same level of cleanliness specified for the item being packaged. Rigid materials with smooth surface finishes can provide the highest degree of cleanliness. Metal foils and high-density plastic films with hard and smooth surface finishes may achieve a good degree of cleanliness when properly cleaned.

i. Sloughing or Shedding -- All materials have a tendency to slough off particles to some degree when subjected to certain conditions. Rigid materials with a hard, smooth surface finish are less susceptible to sloughing. Flexible materials will slough particles to variable degrees when subjected to motion, vibration, flexing or abrasion. The size and quantity of particles generated depend on the type of material, surface finish, and the amount of activity seen by the material. Flexible materials are therefore limited in their use to applications where the particles generated do not exceed the limits specified.

j. Static Charge -- The electrostatic charge formed and retained on the surface of a material whenever two objects contact one another and then are separated results in two undesirable conditions: (1) the charged surface attracts contaminating particles from the adjacent environment, and (2) the high-energy discharge is capable of igniting electroexplosive devices and flammable materials and causes interference in the operation of sensitive electronic components. The amount of charge that a material may acquire is dependent on the surface areas involved and in the types of materials as related to their position in the triboelectric series. A triboelectric series chart of some common materials is shown in Table 8-1. The material uppermost in the series becomes positively charged when contacted or rubbed by a material lower in the series, which becomes negatively charged. Clean packaging materials should possess adequate antistatic properties particularly when they are used with explosive devices.

TABLE 8-1

Triboelectric Series of Common Materials

Positive (+) Charge

Asbestos	Silk	Dacron
Glass	Fiberglass	Vinyl (PVC)
Mica	Aluminum	Polyethylene
Wool	Paper	Teflon
Cat fur	Cotton	Nickel, copper, silver
Nylon	Wood, iron	Brass, stainless steel
Viscose	Chrome	Sulfur
Rayon	Acetate	Platinum, mercury
Lead	Lucite	India rubber

Negative (-) Charge

Effective antistatic properties can be incorporated in fabrics and plastic films by adding antistatic agents. Two techniques commonly used for adding the antistatic agents are: (1) coating the material or (2) incorporating an internal additive during the manufacturing process.

Films and fabrics coated with an antistatic agent are not considered acceptable for clean packaging due to a tendency of the antistatic particles to slough. In some instances, the antistatic properties of the coating agent are degraded considerably when exposed to certain environments.

Plastic films with an antistatic agent as an internal additive are considered satisfactory for clean packaging materials. Care must be exercised in the film formulation with an antistatic agent to prevent sacrificing other characteristics or properties of the film. The retention of antistatic properties for an extended period of time will vary with the different plastics, the agent used, and the environments to which it is exposed. Antistatic polyethylene and nylon films show some loss of antistatic properties when exposed to strong fluorescent lighting and exposure to ultraviolet light. Direct sunlight accelerates this loss considerably.

k. Flammability -- The degrees of flammability may be expressed as flammable or burning, self-extinguishing or slow burning, and nonflammable or nonburning. Clean packaging materials should be either nonflammable or self-extinguishing to assure integrity of the package and reduce hazardous conditions.

Flame retardancy of plastic films, which do not normally possess the desired degree of this characteristic, may be achieved by adding flame-retardant chemicals to the formulation of the plastic. These additives are generally classified into two types: (1) additives which are blended physically with the material, and (2) modifiers which are reactive and unite chemically with the plastic. The additive types may be used in many different plastics, while the reactives are usually tailored for a specific plastic. Combining flame-retardant additives with the various plastics may affect other characteristics such as color, flexibility, tensile strength, and softening point. Therefore, careful formulation is essential to prevent degradation of other essential characteristics.

l. Interaction with Hazardous Materials -- The effect that the packaging material may have when in contact with certain hazardous materials is a required consideration. The resulting interaction may be evident by temperature increases, ignition, combustion, dissolution, etc. The materials which present probable hazardous interactions include: hypergolic propellants (i.e., unsymmetrical dimethylhydrazine - UDMH; monomethylhydrazine - MMH; nitrogen tetroxide - N_2O_4); liquid oxygen - LOX; gaseous oxygen - GOX; chemicals; volatile liquids; and other explosive and highly flammable materials.

8.2.4 Evaluation of Plastic Films

Evaluating materials for the qualities essential to clean packaging reveals that such materials readily available and economically practicable are somewhat limited.

The plastic films being more economical are widely used; however, those which possess the qualities essential to intimate closures for precision-cleaned items are quite limited. The plastic films which are cleanable to a reasonable degree and limited in sloughing are currently the most commonly used.

Films used for clean packaging purposes are available from the producers normally as only "commercial clean" which is inadequate for this application. Precision-cleaned films are available which can meet the cleanliness requirements for many clean packaging applications. The levels of cleanliness as specified by the supplier of such films should be checked to assure conformance with the requirements of the specific application. Some of the films which possess the necessary qualities for clean packaging are described in the following paragraphs:

a. Polyethylene -- This film is widely used because it is available economically in many types, sizes, and thicknesses. Its disadvantages are a lower strength than most films and a higher degree of sloughing. It distorts readily when in contact with oils.

(1) Polyethylene, Ordinary, Clean -- Low to medium density polyethylene film, natural color, 6-mil thickness, without talc or starch slip agents. (Antistatic and fluorescent types are available, and colored for identification.)

(2) Polyethylene, Antistatic, Clean -- Pink nonfluorescent polyethylene film, 6 mils thick, containing an internal organic antistatic additive throughout the film which renders all surfaces sufficiently conductive to bleed off static charges and eliminates particle attraction or spark-discharge hazard due to static electricity. Films surface-treated or sprayed with antistatic compounds are not acceptable, since such coatings rub off or interfere with heat sealing.

(3) Polyethylene, Daylight Fluorescent, Clean -- Bright fluorescent pink polyethylene film, 6 mils thick, containing a pigment which fluoresces orange under black light, for ease in identifying those particles sloughed from the film surface of a bag or wrap as opposed to those from other sources.

b. Polyamide (Nylon 6) -- This film is high in abrasion and flex resistance, and thus creates the least self-contamination problems among films in common use. A limitation of Nylon 6 is that it does not provide a good moisture barrier. This characteristic can be used to advantage when a desiccant is used between the intimate and environmental packages. Because it is a poor barrier to moisture vapor, however, a nylon intimate package normally requires an environmental package such as polyethylene.

(1) Nylon, Ordinary, Clean -- Nylon 6 (or blends of Nylon 6 and Nylon 6, 6) polyamide films, natural color, 2-mil thickness, without talc or starch slip agents. Nylon film is most resistant to sloughing of particles due to flex and abrasion of all films in clean packaging use, and is therefore preferred as the intimate package in contact with all clean surfaces or items except those parts destined for LOX or GOX service.

(2) Nylon, Antistatic, Clean, Heat Stabilized -- Orange fluorescent transparent nylon film, 2 mils thick, containing an organic antistatic agent throughout the film to eliminate static charging (see Polyethylene, Antistatic, Clean), plus a heat stabilizer enabling the film to withstand dry heat sterilization cycles of 300°F for 12-hour periods and up without marked degradation. Ordinary nylon browns and embrittles in short periods under this temperature.

(3) Nylon, Daylight Fluorescent, Clean -- Yellow-green fluorescent nylon film, 2 mils thick, containing a pigment which fluoresces blue-white under black light, to aid in identifying those particles sloughed from the intimate package surface as opposed to those from other sources.

c. Fluorohalocarbon (Aclar) -- Of the clean packaging films, Aclar is the only one compatible with LOX. Aclar 33C, 22A, and 22C meet the requirements of MSFC-SPEC-456 for packaging all pneumatic components requiring LOX-compatibility, but Aclar 33C is generally used because of superior cleanability. Aclar has the disadvantage that it abrades more readily than nylon and, therefore, has more tendency toward self-contamination. However, sloughed particles of Aclar are LOX-compatible while particles from other films and foils can constitute a potential explosion hazard under impact in LOX service.

(1) Aclar, Clean -- Fluorohalocarbon copolymer, largely chlorotrifluoroethylene copolymerized with small quantities of other fluorocarbons, unplasticized and without additives. It is clear and colorless, 2 mils thick (although other gages such as 5 mils are available and very occasionally called out), and is available in three grades: Aclar 22A, 22C, and 33C. All grades are certified LOX-compatible under impact test (MSFC-SPEC-106A), but Aclar 33 is preferred for packaging parts designed for LOX service due to its superior resistance to cleaning solvents.

d. Polyester (Mylar) -- This film has excellent resistance to abrasion and to grease and oils, and relatively low permeability of gases and water vapor. Particle sloughing resulting from flexing is somewhat higher than nylon, and sealing by normal heat-sealing methods is difficult to achieve. This film may be preferred in some applications provided the required cleanliness level is attainable and an effective seal of the package can be achieved.

e. Aluminum Foil -- Although this is not a plastic film it is sometimes considered for use with the plastic films for clean packaging applications. Household grade aluminum foil has an oil film on the surface that is not acceptable for clean packaging or for LOX or GOX use. Clean oil-free foils are available which can pass the LOX impact test as a sheet sample, but the high rate of particle sloughing from abrasion and flexing produces aluminum particles which are not compatible with LOX under impact. It is not heat-sealable, it is opaque, the surface oxides may be abrasive to precision finishes, and contact with dissimilar metals can contribute to corrosive action. Aluminum foil as an intimate packaging material may find very limited application. However, as an environmental package, or intermediate package, its high

TABLE 8-2

Characteristics of Clean Packaging Films

Material and Color	Trade Name	Application
POLYETHYLENE, Ordinary, Clean Clear		Environmental package over intimate packages made of more expensive materials such as nylon or Aclar, to provide outer cushioning and supply missing moisture barrier over nylon bags; to be used as intimate package only in cases where cleanliness levels are not critical. Where heavy objects are to be wrapped, multiple layers of 6-mil polyethylene are to be preferred over one layer of a greater mil thickness.
POLYETHYLENE, Antistatic, Clean Pink	RC AS-1200 Antistatic Poly	Besides use in place of POLYETHYLENE, Ordinary, Clean, the antistatic type should be used in packaging electroexplosive devices such as squibs and actuators, and around electronic devices and components such as field effect transistors and other devices which are capable of being rendered inoperative by static discharge. Clean room curtains, covers and drapes, as well as outer bags and wraps for clean intimate bags may be made of antistatic film to minimize attraction of airborne particulate matter. High slip of destaticized surface makes bags easy to open with clean room gloves.
POLYETHYLENE, Daylight Fluorescent, Clean Fluorescent pink	Polyethylene DF	See POLYETHYLENE, Ordinary, Clean; also as a tracer technique for identifying particles sloughed from the film surface as opposed to those from other sources.
NYLON, Ordinary, Clean Clear	Nylon C, UCF Nylon, RC Clean Nylon, Microclean Nylon, Others	Intimate package and cushioning in critical clean packages, including bearings, precision clean parts, and all items requiring the ultimate in particulate cleanliness. Nylon bags may be steam-sterilized but not using dry heat, unless specially stabilized. (See NYLON, Antistatic, Heat Stable, Clean.)
NYLON, Antistatic, Clean, Heat Stabilized Fluorescent orange	RC AS-2400 Antistatic Nylon	Dry heat sterilization of clean components without the necessity of removing them from the sealed bag. Antistatic drapes and covers requiring higher temperature resistance, lower flammability, higher clarity, and greater toughness than that offered by antistatic polyethylene. Intimate bags where particle attraction must be minimized. See NYLON, Ordinary, Clean. See POLYETHYLENE, Antistatic, Clean.
NYLON, Daylight Fluorescent, Clean Fluorescent yellow-green	Nylon DF	See NYLON, Ordinary, Clean; also used as a tracer technique for identifying sloughed particles.
ACLAR, Clean[1] Clear	RC Clean Aclar, Microclean Aclar, Others	Intimate package and cushioning in contact with clean parts destined for LOX or GOX service, or which will contact nitrogen tetroxide or similar violent oxidizers, where particles sloughed from other films and foils can constitute an explosion or ignition hazard under impact. Of all plastics, only fluorocarbons (and not all of them) are LOX-compatible. Fluorocarbon films are highly resistant to moisture vapor.

[1]Aclar is Allied Chemical Corporation's registered trade mark for its fluorohalocarbon films.

TABLE 8-2
(continued)

LOX/GOX Compatibility	Sealability	Forms Available	Applicable Specifications
Sloughed particles are pure hydrocarbon; NOT LOX- or GOX-compatible	Broad melting range; sealable with hot-bar constant heat and thermal impulse sealers, and ultrasonic means	Flat roll stock Seamless tubing Edge-sealed tubing Bags	LP-378 KSC-C-123(D)
See POLYETHYLENE, Ordinary, Clean	See POLYETHYLENE, Ordinary, Clean	Flat roll stock Seamless tubing Edge-sealed tubing Bags	LP-378 KSC-C-123(D) (specify pink color)
See POLYETHYLENE, Ordinary, Clean	See POLYETHYLENE, Ordinary, Clean	Flat roll stock Seamless tubing Bags	LP-378 KSC-C-123(D) (specify DF)
Minimal sloughed particles are NOT LOX/GOX-compatible	Melting point about 425°F; requires use of thermal impulse sealers, or RF or ultrasonic means	Flat roll stock Seamless tubing Edge-sealed tubing Bags	KSC-C-123(D) MSC-C-12A
See NYLON, Ordinary, Clean	See NYLON, Ordinary, Clean	Flat roll stock Edge-sealed tubing Bags Large seamed shapes	KSC-C-123(D) MSC-C-12A
See NYLON, Ordinary, Clean	See NYLON, Ordinary, Clean	Flat roll stock Bags	KSC-C-123(D) MSC-C-12A
Certified LOX-compatible; most nearly GOX-compatible clean packaging material	Melting point 350° to 390°F; needs thermal impulse, RF or ultrasonic sealing; hot-bar and rotary band seals sometimes used; Aclar seals are somewhat brittle and tend to zipper, may be reinforced on outside by pressure-sensitive tape.	Flat roll stock Edge-sealed tubing Bags (sealed on all edges, never folded due to brittleness)	KSC-C-123(D) MSC-C-12A MSFC-SPEC-456 MSFC-SPEC-164 LP-001174 (GSA-FSS)

TABLE 8-3

Characteristics and Properties of Selected Plastic Films

Film Type	Thickness Range (in.)	Tensile Strength (psi) (1)D882-61T	Permeability: (2)W-V-T-R (1)E-96-635(E)	Permeability: (3)Gases (1)D1434-63			
				CO_2	H_2	N_2	O_2
Polyethylene (Low to Med Density)	0.0003 and up	1500-3500	0.7-1.5	2700	-	180	500
Polyethylene (High Density)	0.0004 and up	2400-6100	0.3	580	-	42	185
Polyamide Nylon 6	0.0005 - 0.030	9000-18000	5.4-20 @ 38°C	45	250	6	25
Nylon 6/6	0.005 - 0.020	9000-12000	3-6	9.1	-	0.35	5
Fluorocarbon	0.0005 - 0.020	2500-3000	0.4	1670	2200	320	750
Polycarbonate	0.0005 - 0.020	8400-8800	11.0	1075	1600	50	300
Polyester	0.00015-0.014	20000-40000	1.7-1.8	16	100	1	6
Polypropylene	0.0005 and up	4500-10000	0.4-1.0	800	1700	48	240
Polyurethane	0.0003 and up	5000-9000	45-75	465	-	41	75
Polyvinyl Fluoride	0.0005 - 0.002	7000-18000	3.24	15	58	0.25	3
Polyvinyl Chloride	0.0005 - 0.08	1400-5600	4.0	75	-	20	500

NOTES:

(1) ASTM test method numbers, values given are the average or approximate that may be expected of that type film. Actual values of a specific film will vary between suppliers and between different lots from the same supplier.

(2) Water-vapor-transmission-rate - gm/100 in.^{2}/24 hr/mil/@ 25°C

TABLE 8-3
(continued)

[4]Resistance to							
Grease and Oils [1]D722-45	Acids [1]D543-63T	Heat (°F) [1]D759-48	Abrasion and Sloughing	Flammability [1]D1433-58	Precision Cleanable	Heat Seal Temp. Range (°F)	[5]Hazardous Materials Effects
P to G	E	180-220	P	Slow burning	Yes	250-400	UDMH, MMH, N_2O_4 - None; Not for LOX-GOX
G to E	E	250	G	Slow burning	-	275-400	
E	P	200-400	E	Self-extinguish	Yes	380-450	UDMH, MMH - None; N_2O_4-dissolved; Not for LOX-GOX
E	P	-	-	Self-extinguish	-	-	
E	E	400-525	G	Nonflammable	Yes	540-700	UDMH, MMH, N_2O_4 - None; For LOX-GOX
G	G	270	E	Self-extinguish	-	400-430	-
E	G	480	E	Slow burning	-	325-450	-
G	E	270-300	P	Slow burning	-	285-400	-
E	G	190	-	Slow burning	-	300-350	-
E	E	220-250	G	Slow burning	-	400-425	-
E	G	150-200	-	Slow burning	-	300-400	-

[3]Gas permeability - cc/100 in.^{2}/mil/24 hr/atmos/@ 25°C.

[4]Rating code as related to other types of film; E - Excellent, G - Good, P - Poor.

[5]Hypergolic propellants; UDMH - Unsymmetrical Dimethylhydrazine; MMH - Monomethylhydrazine; N_2O_4 - Nitrogen Tetroxide; LOX - Liquid Oxygen; GOX - Gaseous Oxygen.

resistance to grease, oils, acid, heat, nonflammability, and limited permeability of gases and vapor may make it desirable in some applications. Where an opaque material is required, aluminum foil or an aluminized surface on a plastic film may fulfill this requirement.

f. Composite Films -- The structuring of two or more different types of films to form a composite film has the advantage of combining in one film the characteristics of two or more individual films to provide the needs for a particular application. Two methods of structuring are utilized for composite films: the mechanical lamination and the extruded or formed composites.

Mechanical lamination consists of sandwiching together the different types of films with special adhesives, by thermal lamination, or extrusion coating one film on another.

The extruded composite films are two or more films produced simultaneously, and formed into a multilayer structure while still in amorphous and semimolten states during the manufacturing process.

Pertinent information on some of the above characteristics and applications of the most commonly used clean films is given in Table 8-2.

Those characteristics and properties which are considered most significant to clean packaging films are shown with a selected list of plastic films in Table 8-3.

8.3 Closure and Packaging Methods

The preceding paragraphs have discussed the general preparations and materials for clean packaging. The next step in clean packaging is the application of these materials in such a manner as to provide a sealed, identified, and contamination-protected item. Depending on the item and its cleanliness requirements, packaging can range from a fairly simple operation to a complex process.

Packaging techniques have been developed which, when coupled with a knowledge of the elements of clean packaging, can produce a package as clean as the material technology presently permits. Unfortunately, so far as particulate contamination is concerned, material development has barely kept pace with cleanliness requirements and lags behind surface cleaning capabilities.

A complete clean package may consist of one or more elements dependent on the particular requirements. These elements are: intimate cushioning - used as required; intimate package - used to exclude exterior contaminants and maintain cleanliness of item; and environmental package - used over the intimate package when that package does not provide adequate environmental protection. The following paragraphs describe the closure and packaging methods for constructing these elements of a clean package.

8.3.1 Intimate Cushioning

The purpose of cushioning in clean packaging is to protect the intimate package material from excessive abrasion or rupture due to contact with the item. It differs from the usual concept of cushioning in that it does not necessarily serve as a shock mitigating medium. Any protrusion, sharp corner, or externally threaded section should be adequately cushioned.

Because of the quantity of sharp edges involved, male threaded sections present a unique challenge to clean packaging. Normally they are covered with one or more layers of the same clean material used for the intimate package. Surface area should be kept to a minimum consistent with the need for completely covering the threads and securing the material to the item. There appears to be no specific agreement on how tightly the material should be drawn over the item. It is believed, however, that best results are attained when the material is neither too tight nor too loose but is gently hand-formed over the section. This technique reduces both the material surface area and the amount of movement between the material and the item, but it does not draw the material tight over the sharp edges.

Cushioning material may be secured to the item in several ways as described below. The exact method will depend on several factors such as item configuration, cleanliness requirements of the item external surfaces, and the amount of handling and transportation anticipated.

a. Taping the Cushioning to the Item -- This method involves securing the cushioning materials to the item at all common points. It is most often used on external protrusions which lead to internal surfaces of a component or assembly, and when the cleanliness requirements are primarily intended for the internal surfaces.

   That portion of the tape in direct contact with the part will probably leave an undesirable residue which may have to be removed by further cleaning when the cushioning is removed. The length of the tape used should be sufficient to make an effective bond. If the tape is applied around a protrusion, it should overlap itself by at least 1/4 of the circumference of the protrusion.

b. Taping Only Over the Cushioning Material -- This is similar to Method a. above, except that the tape does not contact the surface of the item. The cushioning is applied in the same manner, hand-formed over the protrusion, and held in position while the tape is secured. This method eliminates the problem of adhesive residue on the item.

   The cushioning must be of sufficient length to allow space for taping. The tape must be stretched and kept under tension as it is applied in order to provide adequate holding power when the tension is released. In this case, the tape should overlap itself by at least 1/2 the circumference of the protrusion.

c. Tying the Cushioning to the Item -- Strips, ribbons, or monofilament cord of clean packaging material may be used to secure the cushioning if tape is not acceptable. This is applied in much the same manner as described in b. above. While this method offers the advantage of eliminating the tape, it also has two distinct disadvantages. It presents more opportunity for particle sloughing both from the increased amount of material and from the tying operation. Further, unless the tie is strongly knotted, it may come loose during subsequent handling.

Closure plugs, caps, and covers which sometimes perform a cushioning function are discussed in Paragraph 8.3.2. Examples of the use of cushioning material are presented in Figures 8-1 and 8-3.

8.3.2 Intimate Package

Significant factors in determining the methods and procedures for preparing an effective package are cleanliness requirements, shedding of the barrier material, and size and configuration of the item. Some typical methods of making an intimate package are described in the following paragraphs. Variations and combinations of these simple package forms should be considered to provide the most effective package for any given application. In all packaging operations, the item and the package material must be handled in a manner that will essentially preclude contamination.

a. Film Wrap -- The entire item is enclosed in a plastic film envelope, bag or tube. For this type package, all surfaces of the item must be cleaned to the same level.

The film should be gently hand- or vacuum-formed around the item to achieve the minimum of package volume. Seal the film as close as possible to the item without causing undue stress which might damage either the item or the film.

Prior to final sealing of the package, the interior of the package and the item may be purged by directing a stream of filtered dry nitrogen or other inert gas into the package at a pressure, volume, and period of time which are adequate to completely replace the original atmosphere of the package with the gas. The final seal of the package should be accomplished immediately after purging to assure a maximum entrapment of the purging medium.

Some typical applications of this type of film package are shown in Figures 8-1, 2, and 3.

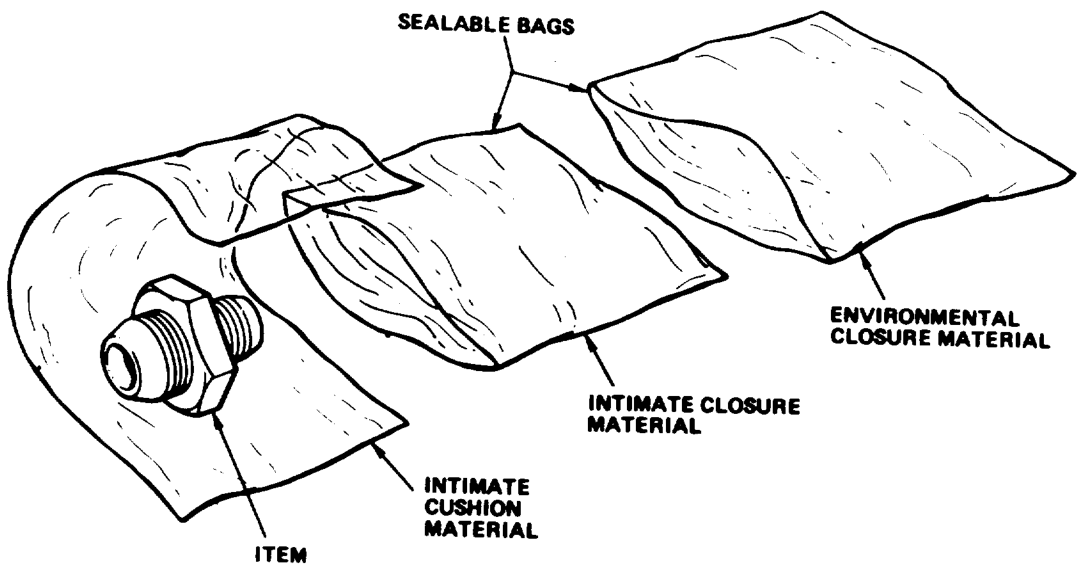

Figure 8-1. Typical clean package film wraps

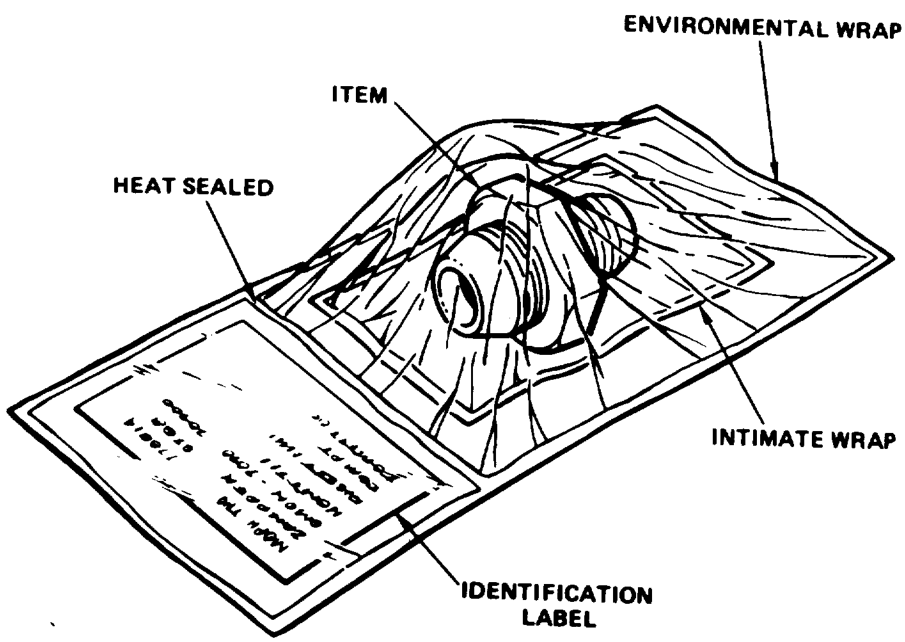

Figure 8-2. Film wraps with identification

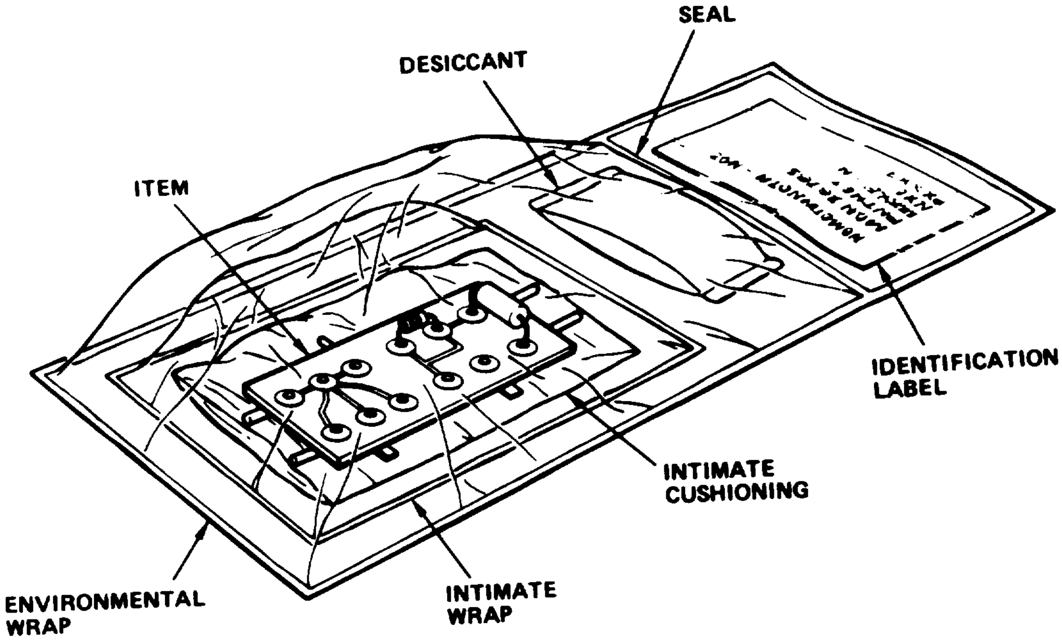

Figure 8-3. Film wraps with desiccant

b. Film Closure -- By this method, the open connections and ports leading to cleaned interior surfaces of parts, ducts, fittings, etc. are closed with plastic film.

One or more layers of clean film are placed over the opening and formed around the outside of the part and secured by tape or tie placed over the film and drawn tight. A film tube of adequate size to fit over the opening and extend down the side of the part may be used in place of film sheet.

Adhesive-backed tape may be used to secure the film snugly around the part to effect the seal. The tape should be placed entirely on the film and not extend onto the part unless its contact is specifically acceptable for subsequent operations and assembly. However, it should be noted that a good hermetic seal may not be effected. Therefore, additional environmental wraps to provide the necessary protection may be required.

Prior to final sealing of the opening(s), the interior of the part may be purged with filtered dry nitrogen or other inert gas. Purging should be performed in a manner to ensure that the inside atmosphere of the part and the closure(s) is completely replaced with the gas. Final sealing of the closure(s) should be performed immediately following the purging.

Some typical applications of this type of film closure are shown in Figure 8-4.

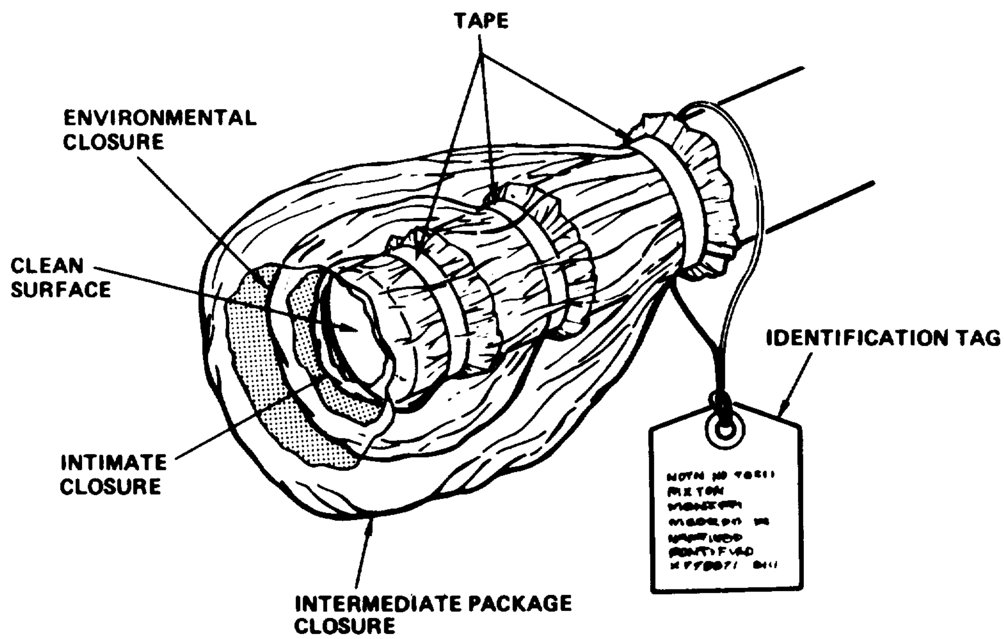

Figure 8-4. Typical clean package film closure

c. Film Closure with Protective Disc or Cover -- The size of openings in parts may require some form of protection for the plastic film closure. Discs or slip covers made of rigid plastic or similar, smooth, clean material may be used. If the disc or cover will be in contact with the part, metals should be carefully selected to preclude the possibility of galvanic corrosion.

The disc should have a slightly larger outside diameter than the opening on which it is to be used. With the film closure drawn smooth over the opening, the disc is centered over the opening on top of the film. Tape is placed around the perimeter of the disc, partially on the disc and partially on the film covering the outside of the part, with the tape drawn tight to hold the disc securely in place. In some situations, the disc may be placed directly over the opening, the film drawn smooth over the disc, and the tape placed over the film to hold the disc and film in place. A second wrap of tape may be required near the end of the film to provide a better seal and hold the film in place.

Covers used should be of adequate size to slip over the outside diameter of the part at the opening. With the film closure drawn smooth over the opening of the part, the cover is slipped over the film and part with the head of the cover seated firmly against the end of the opening. The cover flange is sealed to the film with tape placed partially on the flange and film and around the circumference of the closure. In some instances, the cover may be placed directly over the opening with the film closure over the cover in a manner similar to the disc and film closure.

Purging when required should be performed as described for the film closure.

Typical closures utilizing discs and covers are shown in Figure 8-5.

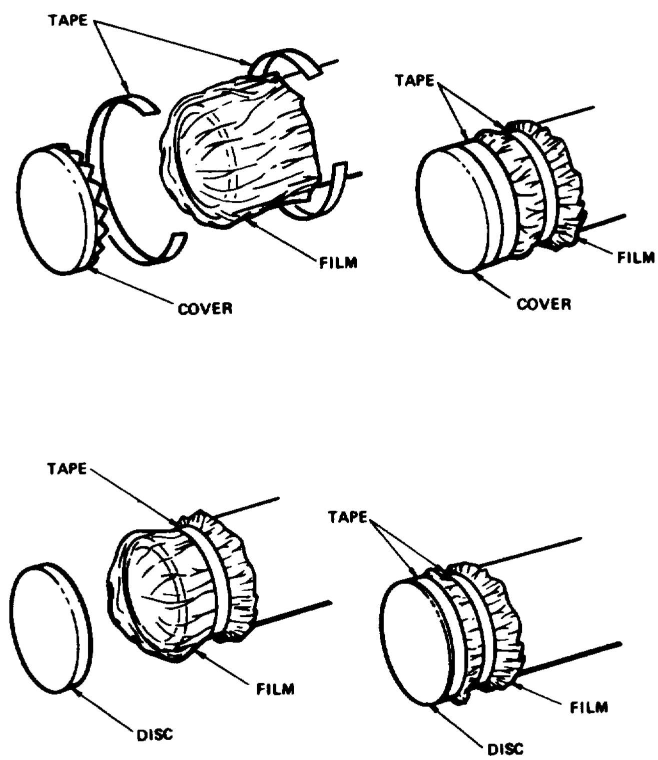

Figure 8-5. Film closure with disc or cover

d. Gasket and Plate Closure -- Bolted flange-type connections and openings leading to precision-cleaned interior surfaces may be sealed using a gasket and closure plate.

The gasket should be made of clean film or other material compatible with the end use of the item and of adequate thickness to provide a compression seal to the flange. One or more sheets of gasket material may be used to obtain the desired thickness.

The diameter of the gasket and closure plate should be equal to the outside diameter of the flange. Holes should be of equal size and have the same hole pattern as the corresponding holes in the flange.

The closure plate should be a rigid material of adequate thickness and flatness to assure uniform compression of the gasket on the flange.

If attachment hardware such as bolts and nuts is of a metal dissimilar to that of the flange, bushings and washers of nylon or similar material should be used to prevent galvanic corrosion. The bolts and bushings should fit loosely in the holes to preclude galling or shredding.

Purging the interior of the item with filtered dry nitrogen or other inert gas may be accomplished prior to sealing by directing the gas into another opening in the part and allowing the gas to escape around the gasket, or allow space between plate/gasket and flange to direct the gas into the interior at this point. Purging should be performed in a manner to completely replace the inside atmosphere with the gas.

Immediately following the purging operation, the closure should be made with the film gasket over the flange face and the closure plate over the gasket. With holes aligned, attachment hardware is installed and torqued to recommended values for the size and type used. This is followed by placing tape over the circumference of the plate, gasket, and flange.

A typical closure with plate and gasket is shown in Figure 8-6.

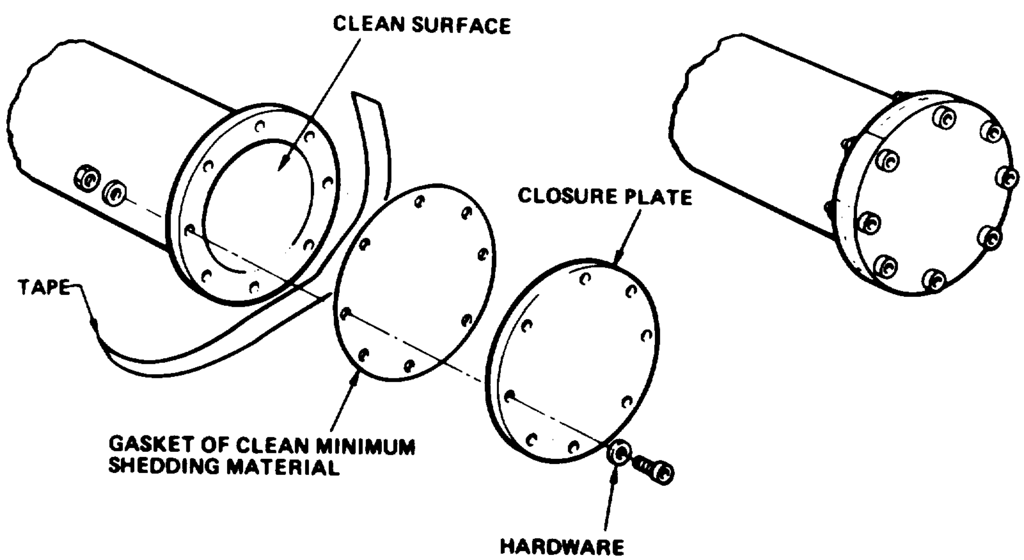

Figure 8-6. Clean package closure plate

e. Threaded Cap or Plug Closure -- Threaded connections with openings leading to clean interior surfaces may be sealed with a threaded plug for female thread connections or a threaded cap for male thread connections. O-rings or gaskets may be used in conjunction with the caps and plugs for effective sealing. This type of closure has limited application due to the inherent characteristic of particle generation by the connecting and disconnecting of the threaded closures. Careful selection of the closure material and thread profile will aid in minimizing particle generation, and preventing galvanic corrosion.

A clean cap or plug should be carefully mated to the connection by applying a minimum of torque to seat and seal the closure. Excessive torque increases the probability of particle generation in the threads due to galling and shredding of the thread surfaces.

Prior to sealing the closure, the interior of the item may be purged in a manner similar to that described in d. above.

Typical closures with threaded cap and plug are shown in Figure 8-7.

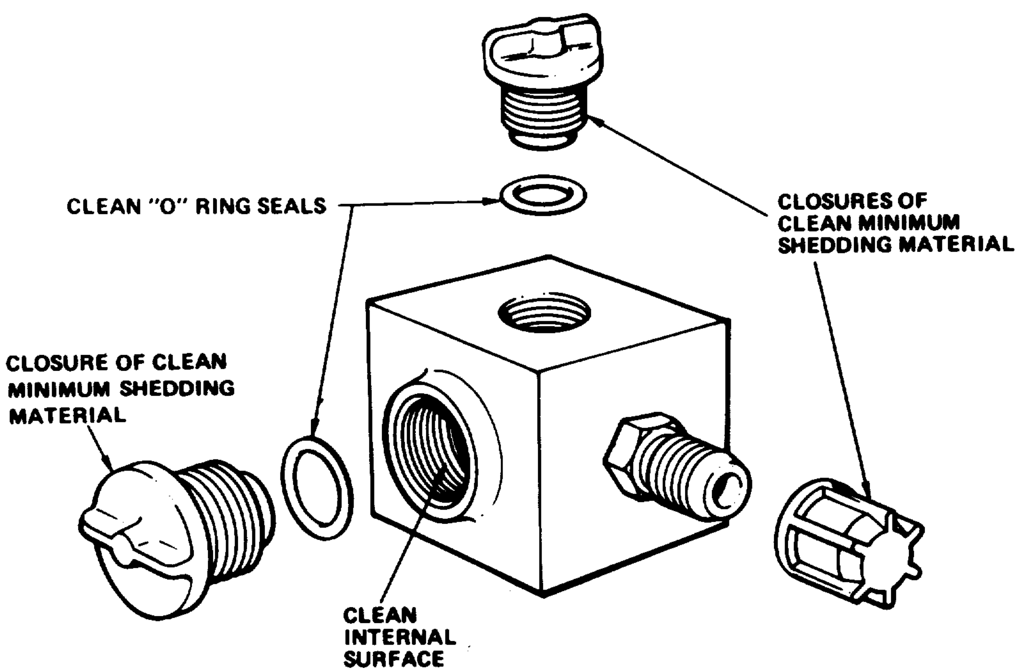

Figure 8-7. Typical threaded closures

f. Containers of Rigid Material -- Enclosure of a part or device in a container of this type is frequently employed as a specially designed encapsulated package in which the device is mated to the package in a manner to enhance its operation in the completed system. However, the utilization of rigid materials for the preservation of cleanliness of parts on a more temporary basis offers some advantages and disadvantages described earlier.

   Rigid materials applicable to clean packaging are glass, ceramic, metal, and plastic. The type of device, its configuration, and its materials of construction will, to a great extent, determine the type of package material that can be used. The use of these materials for packaging during in-process handling and storage operations is described in Section 9.

8.3.3 Environmental Package

The selection of the type of material for the environmental package depends on the type and degree of protection needed for its contents. Polyethylene film is frequently used for this purpose. Containers formed of rigid materials may be applicable for this type package and will provide additional physical protection when required.

The operations involved in applying and sealing the environmental package are essentially the same as described for the intimate package in Paragraph 8.3.2. Film wraps and closures should be formed over the intimate package and sealed in a similar manner but not to interfere with or damage the intimate package. Rigid containers may require additional intimate cushioning material, such as dimple wrap, around the intimate package in the container. Sealing may be accomplished using adhesive-backed tape over the juncture of the container parts.

Some variations in the application of the environmental package are described below. The requirements of the individual packaging situation will dictate the particular methods.

a. Desiccant and humidity indicators may be enclosed with the environmental package. The desiccant should be of the nondusting type in cleanable bags, and should conform to MIL-D-3464, Type II. Desiccant bags should be wiped clean with a solvent-dampened cloth before use. An example of an environmental package with desiccant enclosed is shown in Figure 8-3.

b. Identification labels may be attached in the external portion of the package when a plastic film wrap or bag is used. After sealing the package, the label is placed within the excess portion of the film and sealed to retain the label. An example of a package with the label inserted is shown in Figures 8-2 and 8-3.

c. Purging the environmental package may be accomplished prior to sealing, by directing a stream of filtered dry nitrogen or other inert gas into the package in a manner to assure complete replacement of the inside atmosphere with the gas. In some cases, the environmental package is slightly pressurized with the purge gas to provide a cushioning effect. In others, it is hand- or vacuum-formed around the intimate wrap.

Examples of the environmental package in the form of a wrap or closure of plastic film are shown in Figures 8-1, 8-2, 8-3, and 8-4.

8.3.4 Sealing

Methods for effectively sealing packaging materials to assure the integrity of the enclosed clean item depend on the type of material and the closure or wrap. Sealing methods described in the following paragraphs are some which have general application for the common types of wraps or closures. Each particular packaging situation requires individual consideration to select or develop the most effective method of sealing.

8.3.4.1 Heat Sealing

Heat sealing is the simplest and most commonly used method for joining plastic films of the same type or different types and for joining plastic films with some other materials. Heat sealing eliminates the need for adhesives and other forms of mechanical fasteners.

The major techniques of heat sealing which are currently in use are thermal, dielectric, and ultrasonic. There is a preferred method for each type of film; however, many of the films can be sealed by more than one method. An effective hermetic seal can be achieved on most of the plastic films by at least one of these methods. Table 8-4 lists some of the plastic films with the methods that may be used for sealing.

TABLE 8-4

Plastic Film Heat-Sealing Methods

Film Type	Dielectric	Thermal	Ultrasonic
Polyethylene	O	X	X
Polyamide (nylon)	X	X	X
Polycarbonate	O	X	X
Polyester	X	O	X
Polypropylene	O	X	X
Polyurethane	X	X	O
Polyvinyl chloride	X	X	O
Fluorohalocarbon	X	X	X

X - sealable
O - not sealable

a. Thermal Sealing -- Thermal sealing is the direct application of heat to the films for a sufficient period of time for the films to melt and fuse together. The preferred sealing method for clean packages is thermal impulse sealing wherein a die is quickly heated after coming in contact with the material and the proper pressure is applied. This heating cycle is then followed by a cooling period with the material held in place by pressure on the die, which assures an effective seal without distortion or separation.

In the hot-bar method the film to be sealed is placed between two plates or dies, one or both constructed with cartridge or strip heaters. Temperature-sensing devices are mounted close to the sealing surface of the dies to control the temperature, as effective control of the temperatures determines the strength and quality of the seal. A press is employed to apply pressure to the dies for the time required for the films to melt and fuse, and then the dies are separated and the sealed film allowed to cool. Continuous seams can be made by passing the films between hot rollers under pressure or over a hot platen, and then between cold rollers under pressure. Films which can be effectively sealed by this method are generally those which can be removed hot from the die without distortion or separation of the seal. Nylon and Aclar are difficult to seal by the constant heat, hot-bar method.

In both methods the flatness of the die faces, which contact the material, is important to ensure uniformity of pressure applied in all areas for a homogeneous seal. Materials of construction for dies should be similar throughout to avoid bimetallic distortion due to differences in the thermal coefficient of expansion of dissimilar materials. Effective use of insulating materials and barriers is required for good temperature control.

b. Dielectric Sealing -- This method utilizes radio frequency (RF) to produce the heat and fusion process. The films being joined act as the dielectric between the plates of a capacitor which are the die face and the press platen. The plates are connected to an RF generator which induces molecular vibrations within the plastic and the resulting friction produces heat uniformly throughout the film seal area. Since the plates or dies are cool, heat loss to the plate cools the film surfaces so that only the interfaces melt and fuse together forming a bond.

The frequency allocated by the Federal Communications Commission (FCC) for unlimited operation of this equipment is 27.12 MHz. This frequency provides effective sealing of most materials sealed by this method. Operation at other frequencies requires that the radiation be maintained below the level of interference specified by the FCC.

The major advantages of the dielectric method of sealing are the speed, ease, and simplicity of producing effective seals with good reproducibility and reliability. After sealing, the material can be cooled under pressure to achieve maximum seal strength and quality.

Dielectric sealing is normally used only in the manufacturing process for high volume plastic products, due to the high investment required for the device and the shielded facilities. It is not used generally for clean packaging applications.

c. Ultrasonic Sealing -- Joining plastics by ultrasonics employs high frequency mechanical vibration to produce molecular motion or jostling at the interface. The localized heating results in a natural molecular bond without deforming, distorting, or changing the properties of the material. The material to be joined is placed between a solid anvil and an ultrasonic tool, which provides the mechanical vibrations. The quality of the bond formed depends on the pressure of the tool on the work surfaces, the length of time the vibrations are impressed, and the amplitude of the tool vibration. The thickness of the material and the type of plastic must be considered in designing the sealing procedure.

Ultrasonic sealing can be used for plastic films, but it is generally considered too expensive and too slow a process for this purpose. It is used extensively for bonding rigid plastics.

8.3.4.2 Tape, Ribbons, and Ties

Some types of closures may be sealed adequately by placing adhesive-backed tape, ribbon, or other ties over a flexible film and drawing it tight around an outside portion of the item and securing in place. In some instances, adhesive-backed tape may be used, partially on the package material and partially on the item, to secure a seal. In other instances, the tape may be used to seal the opening in the package material.

The use of adhesive tapes should be in a manner that will not contribute to the contamination of the clean item or surface.

8.3.4.3 Compression Seals

Gaskets, O-rings, and similar type materials may be used to form a seal over or around a closure on an item or between two parts of a rigid container. Material used for this type seal should be clean and of a type that will not contribute contamination.

A means for compressing the seal is required, and the mating surfaces must be relatively uniform to assure uniform pressure over the seal area.

8.3.4.4 Integrity Seals

Seals or decals of a tamperproof type may be applied over the closing seal area of a package. These seals are used as a means of detecting the violation or tampering with the clean package seal. Some form of marking is usually included on this seal such as date and place used or other identification.

The requirements for using integrity seals and the method of application should be specified for each particular type of package seal.

8.4 Verification of Cleanliness

Since the objective of clean packaging is to maintain a specified cleanliness level of the enclosed item, some inspection or testing techniques must be applied to verify that this cleanliness level is, in fact, maintained. Assuming that the item is clean prior to packaging, there are two general types of verification procedures that may be employed. One is monitoring the cleanliness of the intimate packaging materials prior to use and observing clean packaging practices during subsequent packaging operations. The other is monitoring the cleanliness or functional operation of the item upon removal from the clean package. Each of these procedures is described in the following paragraphs.

8.4.1 Monitoring Packaging Materials and Operations

Plastic films are the most commonly used intimate packaging materials capable of being cleaned to the level required for clean packaging. Surface cleanliness of the other materials, when used, may be monitored as described in Section 3. The most generally accepted method for monitoring the cleanliness of clean packaging films is set forth in Specification MSC-SPEC-C-25. Information from this specification is extracted as follows:

a. Visual Inspection -- No evidence of oil, grease, water, solvents, paints, ink, dirt, metal chips, decals, preservatives, or other foreign matter shall be permitted on either the external surfaces or the internal surfaces of packaging materials when inspection is made with the unaided eye. Surfaces shall contain no particulate matter greater than approximately 50 microns in size and should be free from all films other than known innocuous films.

b. Preparation for Test -- The bag shall be heat-sealed across the open end. Using surgical scissors or other extremely sharp blade (to minimize particle generation when cutting), one corner of the bag shall be cut off so that an opening not over 3/4 inch in length is created.

Plastic tubing for precision packaging applications shall be sealed at both ends of a length to give an inside test area of approximately 1 square foot and sampled by rinse test as for bags.

Plastic film (flat roll stock) shall be cut carefully with surgical scissors or other sharp blade to a length and width of 12 inches. The sections shall be folded in half, sealed into a bag form in such a manner as to minimize exposure of the interior to airborne particles, and sampled by rinse test as for bags.

c. Rinsing -- Through the opening, 100 ml of solvent (MSFC-SPEC-237A) per square foot of interior surface shall be introduced from a wash bottle or similar apparatus. A bag having less than 1 square foot of interior surface shall be considered as 1 square foot. The opening shall then be held shut by a practical means. The exterior of the bag shall then be rinsed down with the same agent to prevent exterior particles from being picked up when the bag is decanted. The cleaning agent within the bag shall be agitated by a gentle but rapid sloshing.

d. Collection of Sample -- The cleaning agent within the bag shall be poured out through the same opening (held shut during rinsing) onto a microporous 0.45- or 0.8-micron membrane filter.

e. Testing -- The effluent of the rinse test shall be examined for particulate matter by the particle count method in accordance with Paragraph 4.11.4 of MSC-SPEC-C-14, or ARP 598, or equivalent. The nonvolatile residue of the solvent rinse shall be determined in accordance with Paragraph 4.7 of MSC-SPEC-C-14 (ASTM D2109-64) or an equivalent procedure.

Table 8-5 presents data delineating the levels of surface cleanliness for precision packaging materials. This information is from MSC-SPEC-C-25.

NOTE: The particulate size ranges and quantities specified are designed for certain NASA applications. Requirements for other uses may differ and should be specified accordingly.

Monitoring the clean packaging operation itself is a function of the packaging supervisor. Although this is not a recognized quantitative means of verifying cleanliness, it is nonetheless a practical means of verifying that all reasonable measures have been taken to assure a clean package.

TABLE 8-5

Precision Packaging Materials Surface Cleanliness Requirements

	Particulate Distribution Per Square Foot of Surface Tested		Nonvolatile Residue Per Square Foot of Surface Tested
Level	Size Range (micron)	Quantity (maximum)	Maximum (mg)
1[1]	0-5	Not Counted[2]	1
	5-15	40	
	15-25	20	
	25-50	6	
	> 50	0	
2	0-5	Not Counted[2]	1
	5-15	50	
	15-25	25	
	25-50	10	
	50-100	5	
	>100	0	
3	0-10	Not Counted[2]	1
	10-25	300	
	25-50	50	
	50-100	10	
	100-175	5	
	>175	0	

NOTE 1 - Level 1 shall apply only to nylon films.

NOTE 2 - Particles in this range are not counted; however, any obscuring of the filter grid lines shall be cause for rejection.

Some of the conditions that can be monitored by the supervisor are suggested below:

a. Nothing should be permitted to enter the clean room except essential materials, equipment, and authorized personnel.

b. Personnel should be properly attired.

c. Clean packaging materials (film, bags, etc.) should be covered when not in use.

d. Heat-sealed closures should be made as soon as possible after an item is inserted into a bag.

e. Tools and equipment (knives, cutters, heat-sealer bars, and rollers, etc.) should be cleaned frequently or as dictated by use.

f. Protective covers on clean materials should be resealed if contents will not be withdrawn for a significant period or if they are transported from one clean area to another.

g. Ancillary materials such as desiccant and labels should be brought into the immediate packaging area only when and in the quantities needed for use.

8.4.2 Monitoring the Item

In addition to monitoring the cleanliness of packaging materials and operations, another method is widely used to verify clean packaging, or what may more accurately be called the effectiveness of clean packaging. This is done by monitoring the cleanliness of the part immediately after its removal from the clean package. Several means of monitoring in this fashion are described below:

a. External surfaces and accessible internal surfaces may be visually inspected for contaminants such as particles, moisture, corrosion, scale, and oil. The presence of these contaminants usually indicates improper or inadequate cleaning prior to packaging or rupture of the package during handling or transport. A special light source or borescope is usually needed to inspect internal surfaces.

b. External surfaces may also be inspected with a microscope or by any suitable means of verifying surface cleanliness as described in Section 3. The selection of a particular test method will usually depend on:

   (1) the degree of cleanliness required

   (2) the size and configuration of the item

   (3) the type(s) of contaminants of interest

   (4) the materials of construction.

c. In some systems or assemblies, internal and inaccessible surfaces and confined areas may be monitored by administering a purge gas and testing the gas as it is expelled from the system. A dry, filtered, inert gas should be used for this purpose. The three contaminants most commonly monitored by this method are:

   (1) Particulates -- Entrapped on a membrane filter, and sized and counted by use of a microscope and ocular micrometer.

(2) Moisture -- Measured by a moisture meter in parts per million by volume, by the dewpoint method in degrees centigrade (°C) or other acceptable methods.

(3) Condensable Hydrocarbons -- Measured by the scrubber method or other acceptable method.

Precision clean solvents may also be used in some systems in this same manner to test for particulates and nonvolatile residue.

While this method may be acceptable for some systems, it is not suitable for others because of two serious limitations. Contaminants may be trapped in pockets or dead-end plumbing and therefore are not evident, and test pressures applied to the system may be only a fraction of the actual working pressure.

d. Electrical components and assemblies may be given a functional or continuity check. Any malfunction discovered by this method, however, might be attributable to handling damage.

Another type of monitoring sometimes used involves removing clean packaged components from their package, assembling them into a system, and conducting a functional test of the complete system. This may be sufficient for some applications, but it is not a true test of clean packaging effectiveness because it does not consider handling damage or contamination introduced during the assembly process.

8.5 Specifications

As defined in this handbook, a specification is a document which establishes specific and individual requirements for processes, product, and product performance. Further, it is usually a part of the package of documents constituting the procurement and acceptance contract control for a product or service.

The most distinctive feature of a specification is that it should be limited in scope to the specific requirements of one particular subject. Unless the requirements of two items are identical, a specification covering more than one type of item will be confusing and the result of using it will be less than satisfactory. The only situation in which this principle can be slightly amended is the case of sets of variables being applied to one product. In this way, various properties, characteristics, or requirements can be established as Class I, Class II, Class III, etc.

8.5.1 Specification Preparation

Preparation of a specification involves careful planning and the assembly of all data pertinent to the required conditions about which the specification is being prepared. These conditions are normally stated in the form of requirements and will usually include such items as:

a. A description of the materials to be used in terms of:

- The material itself
- Types
- Grades
- Purity levels
- Properties
- Size
- Configuration
- Special characteristics
- Trade names
- Supporting specifications.

b. A description of processes in terms of:

- The name or identification of the process
- Operating conditions
- Materials used
- Step-by-step procedures
- Supporting specifications.

c. A description of the approved methods for verifying compliance with the specification in terms of:

- Responsibility of various parties for assuring compliance
- The types and number of tests to be conducted
- Sampling criteria, if applicable
- Specific limits for acceptance
- Inspection or test procedures
- Supporting specifications.

The ability to prepare a specification implies an intimate knowledge of the subject, including the practical limits for requirements, and the capability to reduce this knowledge to clear, concise, descriptive statements.

8.5.2 Applicable Specifications

The following specifications are listed by subject for references on clean packaging. In compiling this list, only those specifications directly related to some aspect of clean packaging are included. Several widely used standards are also listed.

Environmental Control:

Federal Standard 209a	-	Clean Room and Work Station Requirements, Controlled Environment
MSFC-STD-246	-	Design and Operational Criteria of Controlled Environment Areas
MSC-STD-C-4	-	Clean Rooms and Work Stations
MIL-STD-1246A (Proposed)	-	Degree of Cleanliness, Cleaning, Controlled Environments, and Protection Requirements

Materials:

O-T-634b	-	Trichloroethylene, Technical Grade
BB-N-41b	-	Nitrogen, Technical Grade
PPP-T-60	-	Tape, Pressure Sensitive, Adhesive
UU-T-81g	-	Tags, Shipping and Stock
MIL-L-10547B	-	Liners, Case and Sheet, Overwrap; Water-Vaporproof or Waterproof, Flexible
MSFC-PROC-404	-	Gases, Drying and Preservation, Cleanliness Level and Inspection Methods
MSFC-SPEC-234	-	Nitrogen, Space Vehicle Grade
MSFC-SPEC-237A	-	Solvent, Precision Cleaning Agent
MSFC-SPEC-456	-	LOX Compatible Film
MSC-SPEC-C-25	-	Cleanliness of Precision Packaging Materials

Methods:

MIL-P-116E	-	Methods of Preservation
MSC-SPEC-C-11A	-	Precision Cleaning
MSC-SPEC-C-12A	-	Precision Clean Packaging
MSC-PROC-C-100	-	Packaging of Precision Clean Parts/ Components
NAS 850	-	General Packaging Standard
NAS 853	-	Field Force, Protection for
NAS 3447	-	Precision Cleaned Items, Contamination Barrier for

Systems Cleanliness:

KSC-C-123D	-	Cleanliness Levels, Cleaning Protection, and Inspection Procedures for Parts, Field Parts, Assemblies, Subsystems, and Systems for Fluid Use in Support Equipment
MSFC-SPEC-164	-	Cleanliness of Components for Use in O_2, Fuel, and Pneumatic Systems
MSFC-PROC-166C	-	Hydraulic System Detail Parts, Components, Assemblies, and Hydraulic Fluids for Space Vehicles, Cleaning, Testing, and Handling
MSFC-PROC-195	-	Cleanliness Level Requirements and Inspection Methods for Determining Cleanliness Level of Gas Bearing, Gas Supply, and Slosh Measuring System
MSFC-10M01671	-	Cleanliness Levels, Cleaning, Protection and Inspection Procedures for Parts, Field Parts, Assemblies, Subsystems, and Systems for Pneumatic Use in Support Equipment

Identification:

MIL-STD-129D	-	Marking for Shipment and Storage
MSC-SPEC-C-3A	-	Decals, Certification of Cleanliness
MSC-SPEC-M-1A	-	Marking and Identification

Miscellaneous:

MIL-STD-105D	-	Sampling Procedures and Tables
MIL-S-4461C	-	Sealing Machines, Heat, Bench, and Portable
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SECTION 9

MAINTAINING PRODUCT CLEANLINESS

Throughout industry, aerospace and medicine, an increasing amount of emphasis is being placed on achieving cleanliness. In view of the growth of microelectronics, the need for higher reliability, and the control of disease, this trend seems destined to continue. Yet, achieving cleanliness is only a means to an end. Unless this cleanliness can be maintained to and through the point of use of the clean object, all of the contamination control efforts in achieving a high degree of cleanliness are of little value.

Ideally, an item with high cleanliness requirements should be fabricated, cleaned, assembled, inspected, and afforded some means of protection within a single, clean, environmentally controlled area. Since this is not practical in many instances, other means must be employed to prevent recontamination. Some of the situations encountered which normally require a protective measure to be instituted are:

a. Delays between critical processing operations

b. Movement from one processing station or clean area to another

c. Inspection and testing to verify both cleanliness and function

d. Unpackaging and further assembly

e. Temporary or long-term storage and transport

f. Maintenance, replacement or service operations, sometimes under adverse environmental conditions.

Clean packaging as described in Section 8 is a widely used means of maintaining cleanliness. It can be applied within a clean processing area and will provide protection for an indefinite time. Unfortunately, however, it can be costly, it sometimes is not completely satisfactory, and it may not be applicable to some of the situations noted above. This section, therefore, describes some of the other means by which cleanliness may be maintained.

9.1 In-Process Handling

Situations in which adequate contamination control may be difficult to maintain include transportation between work stations, actual assembly operations, and progressive temporary storages incident to the manufacturing cycle. Situations of this type should be minimized through effective layout of the processing facilities. When a condition of this nature cannot be eliminated, the items should be packaged, enclosed in clean containers, or conveyed through environmentally controlled tunnels to other clean areas.

Carts or other wheeled vehicles used to transport clean products from one area to another should be excluded from clean rooms, if possible. Otherwise, products in containers should be introduced into a clean room by means of a pass-through. There may be instances when the size or weight of an object will necessitate its being taken into a clean room by mechanized conveyances such as dollies, lift trucks or cranes. Lift trucks used for this purpose should be the hand-operated, hydraulic type or those propelled by battery-powered motors. Lift trucks with internal combustion engines should be excluded from environmentally controlled areas.

Another alternative, when dealing with large objects, is to essentially move the clean room over the object. This can be done by using a vertical laminar airflow portable curtain unit as described in Paragraph 5.6.2. A further variation, which might be considered when large objects are involved, is to move the object into the open end of a horizontal laminar airflow tunnel.

9.2 Handling Containers

Containers for moving clean products through uncontrolled areas may be individual jars or receptacles, compartmented or egg-crated containers, trays, cans or shrouds. Container materials are generally glass, molded plastic or plastic film. Other materials may be used for special product and handling requirements. Whatever their form or material, containers should be:

a. Cleanable -- Capable of being cleaned to the required product cleanliness level

b. Nonshedding -- Resistant to sloughing or shedding and the generation of wear particles

c. Provided with Tight Covers -- Closure methods should be such that the entrance of airborne contaminants is prohibited.

d. Transparent -- Desirable for product identification but not essential

e. Lightweight -- Desirable for ease of handling.

The most important aspects of using containers for clean parts are that the container must first be cleaned to the desired level and that level must be maintained prior to and during use.

If the interval between operations is more than normal processing time, it may be necessary to package the item as described in Section 8 for the period of temporary storage needed.

9.3 Tools and Fixtures

The proper selection, use, and maintenance of tools and fixtures are a vital part of any contamination control program since these items physically touch the parts and assemblies. As with containers, tools and fixtures must be capable of being cleaned and maintained in a clean condition. Surface cleaning methods will remove soils, and temporary packaging or use only within controlled environments will maintain the clean condition.

Essential characteristics of clean facility tooling include:

a. Smooth Surface Finish -- Polished chrome plate is desirable to reduce chipping or peeling

b. Rounded Edges -- Facilitate cleaning, minimizes soil entrapment

c. Self-Lubricating -- Oil and grease collect and hold dirt

d. Minimum Contact Area -- Reduces possibility of contamination.

Parts racks or baskets and tool racks used within clean facilities should be of round wire or rod, open construction, and with hard, smooth surface finishes. Racks of this type facilitate laminar airflow and minimize the collection of airborne contaminants.

Tools should always be placed in or on racks when not in use and should never be placed on a solid work surface. Work-holding fixtures should be readily cleanable, and should support the work piece firmly in a manner such that it does not touch the work surface.

9.4 Unpackaging

Recontamination of a clean packaged item may occur during the unpackaging operation unless the following practices are observed:

a. Remove packing materials such as boxes, crates, cans, blocking and exterior cushioning outside the clean area.

b. Introduce the item with its clean package intact into a clean area.

c. Using a sharp instrument, sever the seal of the environmental package; do not tear the seal off. Remove the intimate package and retain the identification label.

d. Wipe the intimate package or wrap with a lint-free cloth dampened with clean solvent.

e. Sever the seal on the intimate package and gently remove the item, using suitable handling equipment or clean gloves.

f. Carefully remove any cushioning material and tape adhesive that may be on the item.

The item is now ready for verification of cleanliness as described in Paragraph 8.4.2. When test or inspection reveals that the item does not meet the cleanliness requirements for further assembly or use, the item must be recleaned. Recleaning should be performed to the extent necessary to achieve the required cleanliness level, and that level should be maintained through further assembly or use. Recleaning may be instituted as a standard procedure in limited cases.

9.5 Storage and Transportation

Two considerations of vital concern during storage and transportation are maintaining an airtight intimate package around the product, and preventing sloughed particles of the package material from contaminating the product. During movement or transportation, this implies the need for proper cushioning, bracing, blocking, crating, and support or suspension techniques. Outer covers or wraps should have properties capable of protecting the inner package from all environmental elements and physical forces which may be encountered.

The environmental limits of storage and transport conditions should be defined in product specifications, and the packaging and packing should be designed to withstand these conditions. Pertinent considerations for storage facilities and packing requirements should include:

a. Temperature extremes to be encountered

b. The range or control of relative humidity

c. Protection from such environmental elements as wind, rain, snow, dust, and sand

d. Protection from insect and rodent infestation

e. Protection from pilferage, theft or sabotage

f. Proper shelving, bins, and racks to reduce handling and damage and provide a means of segregating material

g. Suitable material handling equipment

h. Vibration and shock limits

i. Inhibition of microbial growth.

9.6 Maintenance and Replacement

It is assumed that precision-cleaned parts or components are protected in some manner when they are put into service. They usually operate within a system or assembly which in itself is clean and is designed to afford protection against the entrance of contaminants. It is only normal, however, that these systems will occasionally need to be opened for maintenance or replacement of parts. Unless adequate provisions are made to exclude contaminants during these operations, recontamination of parts or the system may occur. This in turn may necessitate complete disassembly, cleaning, and reassembly.

The following paragraphs illustrate some of the precautions that may be taken to eliminate or minimize the probability of recontamination during maintenance and replacement operations. These are not all inclusive but are suggested as a guide, and should be supplemented with other measures as dictated by local conditions.

9.6.1 Uncontrolled Enclosed Areas

Enclosed but uncontrolled areas such as rooms, bays or buildings offer protection from the elements of weather and may provide some degree of temperature and humidity control. These areas should be used only when it is impractical to provide a clean environment.

Some of the measures that might be taken to reduce airborne contamination are listed below. Others, equally as applicable, are listed in Paragraph 9.6.2 and should be considered for any uncontrolled area.

a. Remove or shut down any particle-producing activity within the area.

b. Thoroughly clean the area to remove visible dirt and dust.

c. Clean work surfaces with a solvent-dampened, lint-free cloth or sponge.

d. If possible, create an overpressure in the area.

e. Exclude all but required personnel.

f. Garment personnel appropriately.

9.6.2 Unprotected Outdoor Areas

Many field operations are carried on under adverse conditions of weather and exposure. Even under these conditions, an effective degree of contamination control may be required.

The types of apparatus encountered in these situations may include hydraulic lines and systems, gaseous systems (oxygen, nitrogen, etc.), test gear, and associated piping, connections, valves, tanks, and gages.

The following contamination control measures are suggested, when appropriate, for maintenance and replacement operations under field conditions. They are generally, but not necessarily, listed in sequential order.

a. Purge line of working fluid or gas.

b. Erect a protective shelter or portable laminar airflow curtain unit over area where the work will be performed.

c. Use only tools which have been cleaned and packaged or which are wiped with a clean, solvent-dampened cloth at the site, just prior to use.

d. Personnel performing these operations should be properly attired in garments to contain and minimize contaminants from the body.

e. Open the system only at the point or points at which maintenance is to be performed.

f. If possible, maintain a constant pressure on the system with a filtered, dry purge gas. If this is not possible, close the valves on each side of the opening.

g. Clean exposed surfaces around the opening of any visible contamination.

h. Use only certified, clean packaged replacement parts.

i. Do not open the package of replacement parts until they can be installed immediately.

j. If the work is interrupted for any reason, immediately cover the opening using approved closures or covers.

k. In the case of extremely inclement weather, such as high winds, sand or dust storms, or heavy rain or snow, operations should be suspended.

9.6.3 Tanks

Maintenance and replacement operations in tanks present some special problems, in addition to those normally encountered in systems. When practical, the following precautions should be observed:

a. Maintain a positive pressure purge in the tank at all times during these operations.

b. Open only those ports necessary for the operations.

c. Immediately after opening ports, wipe adjacent interior and exterior surfaces with a solvent-damped, lint-free cloth.

d. Clean all tools and instruments prior to their entry into the tank, or use clean packaged tools and remove the packaging just prior to entry.

e. Personnel entering the tank should be completely garmented, including shoe covers and gloves.

f. Personnel entering the tank should be equipped with safety gear, including a clean nylon safety rope and breathing apparatus, if required.

g. A log of each item taken into and removed from the tank should be maintained to assure removal of all tools, equipment, and supplies.

h. Contaminant-sensitive components within the tank should be covered with nylon, Aclar or other compatible covering material.

i. Foam pads may sometimes be used directly under the work being performed to prevent damage to the tank from tools that may be dropped.

j. After completion of the work, the tank should be cleaned thoroughly by vacuuming and/or solvent spraying. Only the vacuum line and cleaning head should be brought into the tank; the unit should remain outside. If a solvent spray is used, a drain port or vacuum drain line must be provided.

k. After being closed, the tank should be purged. Low-pressure purges or blow-downs in a high working pressure tank are usually not effective in removing contaminants.

l. The internal cleanliness should be verified as necessary.

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SECTION 10

PERSONNEL

In contamination control, most discussions of personnel relate to those working in a clean facility because the most serious personnel problems arise and therefore must be properly controlled in such an area. It should be pointed out, however, that personnel other than those working in a clean room can contribute to contamination control. As discussed in Section 2, it is essential that the product designer be aware of contamination control requirements and techniques. Likewise, the manufacturing and packaging engineers, laboratory technicians, and production personnel are all involved and can make their contribution.

It is equally important that people responsible for managing the above functions have a knowledge of contamination control principles and motivate their employees in the proper performance of the contamination control task. Management can either foster a viable contamination control environment or, through indifference, it can render a well-conceived program impotent.

The elements of good employee participation in any contamination control program are:

a. A knowledge of what must be done and how it can best be accomplished

b. An understanding or awareness of the necessity for contamination control and the probable results if it is not applied

c. The creation of a receptive and cooperative attitude in the minds of employees.

10.1 Personnel Contaminants

Both bioclean and regular clean rooms should be restricted areas, with access limited to persons having work-related reasons for entry. Protective clothing is usually mandatory, with the type being determined by the cleanliness level at which the clean room must be sustained.

As the level of physical activity in a clean room increases, the volume of human emission generated will also rise, so it should be the goal of the process and layout engineers to plan for as little human movement as possible. Traffic into and within the clean room must be closely controlled in order to maintain a uniform level of cleanliness within the area.

Man is a constant source of contaminant emission; therefore, measures must be utilized to offset this condition. The types of contaminants generated by man will usually fall in these categories:

a. Skin flakes and scale

b. Fragments of human hair

c. Droplets of moisture from breathing and coughing

d. Lint and starch particles from washable fabrics

e. Fibers and frayed particles of wool, cashmere, or similar loose weave fabrics

f. Cosmetics, including hair spray and very heavy use of aerosol deodorants.

10.2 Personal Hygiene

Any individual afflicted with skin or upper respiratory diseases must not be permitted to work in a clean room. Several physiological and individual physical problems that fall into this category and which may adversely affect clean rooms are:

a. Allergies to synthetic fibers

b. Allergies to solvents and plasticizers

c. Profuse nasal discharge

d. Abnormal epidermal shedding or flaking

e. High acid content in hand moisture

f. Chronic nervousness, itching, scratching, or claustrophobia.

Clean room personnel shall be required to immediately report to their supervisors the existence or occurrence of the following conditions, whether temporary or of unknown duration:

a. Colds, because they induce coughing, sneezing, or unusual nasal discharge

b. Sunburn

c. Chapping

d. Injuries which require bandaging or produce scabs.

Clean room personnel should be asked to cooperate in maintaining a low contaminant emission rate by observing the following rules:

a. Bathe at night, instead of the morning, due to the removal of normal body oils, and increased scaling

b. Wear clean, unstarched, low-shedding undergarments

c. Shave daily and be clean shaven (male employees)

d. Avoid touching, rubbing, and scratching exposed portions of the body

e. Exercise extra effort to rid the pores of the hands of the normal residue of such home duties as starching, immersing hands in flour when baking, plastering, wallpapering, painting, concrete work, or carpentering.

10.3 Personnel Selection

Great care should be exercised in the selection of personnel for work in a clean room. The conditions outlined in Section 10.2 should be used as a basic guide to eliminate those who, after spending the time and effort to partially train them, would normally be unacceptable.

In order to determine the suitability of a potential employee, it is recommended that he be taken to the area where he can actually view the working conditions and garmenting. He should have the employee regulations explained to him, while he is watching the other employees and the type of work they are doing. Training a clean room worker and having him acquire a new and somewhat strange discipline is costly. Anything within reason which will assure a higher percentage of acceptable clean room employees is highly desirable.

10.4 Clean Room Training Program

The importance of a training program for clean room workers cannot be too strongly emphasized. It is a must! This phase of the indoctrination of a new worker, or a worker from another part of the plant, is the basis on which the entire contamination control program is predicated. This phase of the work should, if at all possible, be handled by someone trained in the clean room field, and if that person is not an employee of the company, the results may be much more dramatic. The outsider can place emphasis on facets of the work and human conduct with more telling effect than the supervisor, or someone from the training organization.

The training program should encompass the following subjects:

a. Proper dress for work in the clean room, for both those articles of clothing provided by the individual and by the company

b. Safety precautions--specifically enumerating any hazardous conditions which prevail in that clean room, and any special precautions related to specific materials, products, or equipment

c. Biological precautions, if appropriate

d. Background information on just how widespread is the concern about contaminants, and the high cost of preventing or combating the spread of contamination. This should include a definition of contamination, with adequate examples to assure that the worker is aware of the problem

e. A printed list of the regulations for conduct, and work in the clean room should be given to the worker. Each item should be explained and fully discussed.

10.5 Clean Room Regulations

The recommended regulations deemed necessary for the successful operation of the various facilities, based on the best class of air cleanliness attainable for the type of facility and equipment, are as follows:

a. All types of clean rooms and clean work stations:

(1) No eating, smoking, or chewing gum.

(2) Garments specified as applicable to a given facility must be worn when entering the area.

(3) Only approved clean room paper shall be allowed in the area.

(4) Ball point pens (fine preferred) shall be the only writing implement used in any clean area.

(5) No cosmetics shall be worn by any worker while in any clean area. This shall include: rouge, lipstick, eye shadow and eyebrow pencil, mascara, false eye lashes, fingernail polish, hair spray, and the heavy use of an aerosol deodorant.

(6) Skin lotions or lanolin base soaps should be provided for the employees, as a means of tightening the skin and to guard against epidermal scale.

(7) Solvent contact with the bare skin should be avoided, as most solvents will remove the natural skin oils, and lead to excessive skin flaking.

(8) The use of paper or fabric towels should be forbidden. Wash rooms should have electrically powered, warm air dryers.

(9) Approved lint-free gloves, powder-free finger cots, pliers, or tweezers should be used to handle material or parts if feasible. Fingerprints are a contaminant and should be avoided.

(10) Gloves or finger cots should not be permitted to touch any item or surface that is not known to have been thoroughly cleaned. Specifically, they should not touch any part of the anatomy, covered or uncovered.

(11) No tool or part should be permitted to be placed on the bench or other surface until that surface has been cleaned with a clean lint-free, isopropanol dampened cloth. Other equally effective solvents, compatible with the surface, may be used if isopropanol is not available.

(12) No tool should be allowed to rest on the surface of the bench or work surface, but should be placed on a hardware cloth or perforated metal rack, to guard against contaminants which have settled on the work surface being transferred to the tool.

(13) All parts or material containers, racks, jigs, fixtures, and tools should be cleaned to the same level of cleanliness specified for the product being processed.

b. Nonlaminar airflow clean rooms and clean work stations:

(1) Garments shall be pocketless, lint-free coveralls, with provisions for snugly fastening the neck, wrist, and ankles.

(2) The caps which must be worn, shall be of lint-free fabric, designed to cover the head and hair completely, except for the face--which shall include the eyes, nose, mouth, and chin.

(3) Shoes shall be cleaned and covered with a nonshedding boot-type cover, or changed to approved clean room footwear. If special footwear is provided, they shall not be worn outside the clean room and dressing room.

(4) The use of compressed air, except in hoods specifically designed for that purpose, shall not be permitted. Any operator assigned to such a hood shall have special instructions for its proper use.

(5) Room maintenance, except for vacuuming by a properly garmented employee, shall be restricted to periods when no productive activity is being performed, and when any material or work in process is covered by an approved cover.

(6) Janitorial services shall be performed only by adequately trained and supervised personnel, each of which must be properly garbed.

(7) All equipment which must be brought into the clean room, shall first be thoroughly cleaned, and the use of the equipment in the room shall not generate any contaminants.

(8) Traffic into and within the clean room shall be restricted to authorized personnel and unnecessary movements by the personnel shall be minimized.

c. Laminar airflow clean rooms and clean work stations:

(1) Garmenting may vary with the type of operation being performed, but the minimum garmenting shall be a pocketless, lint-free smock, or coat, which must extend to a minimum of 15 inches below the work surface. The collar and cuffs of the garment shall be equipped to be fastened at the neck and wrists.

(2) Head coverings shall be worn, and shall be capable of completely covering the hair area. If the operation requires the wearer to lean over the work, or move into the airstream between the filter bank and the work piece, the front, sides, and rear neck area shall also be covered.

(3) Special shoes, or shoe covers are not considered necessary for vertical laminar airflow facilities, nor for horizontal airflow installations except when the work is being performed at a point less than 24 inches from the floor.

(4) A face mask may be needed if an operator has a cold, or if the nose and mouth must be brought very close to the work piece, for work on miniature parts.

10.6 The Contamination Control Specialist

Most people became engaged in contamination control activities because of a personal interest, a need for their services, or by direction from their management, rather than through formal academic preparation. They have brought with them many diverse backgrounds in professional training and/or experience. Consequently, most of these people have specialized in only one or another of the many areas involved in contamination control.

From the foregoing, it can be understood why it is difficult to define the role of the contamination control specialist in a manner that will have universal acceptance. As a corollary, it may be very difficult for anyone to attain the status of a true contamination control specialist.

Disregarding these obstacles, however, the following paragraphs attempt to define the experience required, and the educational and personal qualifications, along with the position duties of a contamination control specialist. It is hoped that this information will serve as a guide to those who contemplate entering the field and to those who have a need for such services.

10.6.1 <u>Position Requirements</u>

a. <u>Educational Requirements</u> -- Possess a Bachelors Degree or higher, or the equivalent in experience or training in one of the following: Physics, Chemistry, Mechanical Engineering, Electronics.

   Some formal educational background in all of these fields with a working knowledge and experience in many of the sciences will provide an individual superior to one who has been exposed to only one of the sciences.

b. <u>Specific Knowledge, Training, or Experience</u> -- Product design and manufacturing processes for specific products involved.

   Analysis and procedures for determining required cleanliness levels.

   Analytical techniques and instrumentation for monitoring and measuring the degree of cleanliness.

   Techniques for controlling contamination in the various environments to which the product may be subjected.

c. <u>General Knowledge</u> -- Product development and manufacturing to include:

   (1) design definition and specifications

   (2) fabrication processes

   (3) assembly procedures

   (4) testing and acceptance practices

   (5) packaging

   Contamination control techniques to include:

   (1) identification of contaminants

   (2) environmental factors relating to contaminants

   (3) surface cleaning processes

   (4) purification and cleaning of air, gases, and liquids

(5) air moving and handling equipment

(6) monitoring and analysis methods and instrumentation.

10.6.2 Contamination Control Specialist Typical Activities

The duties of a contamination control specialist will vary in any given situation according to the product, processes, material, environment, and level of cleanliness involved. Furthermore, the contamination control specialist will not usually be located organizationally within the groups in which contamination control programs would be put into practice. In this case, he serves only as a technical advisor and is not in a position to direct or supervise the implementation of such programs. As a function, however, contamination control will generally require the specialist to perform the following duties:

a. Acquire knowledge of all factors (design, manufacturing, packaging, use, etc.) that affect the product from a contamination control viewpoint.

b. Analyze all situations in the complete product life cycle from design through use and develop a contamination control program to meet required cleanliness levels.

c. Analyze the capability of various equipment, materials, and supplies needed for contamination control activities, determine the most appropriate, and direct their procurement.

d. Develop contamination control processes and instrumentation for specific applications.

e. Call on specialists to furnish highly specialized technical assistance in resolving unique problems.

f. Establish working relations with other internal and external organizations to promote attainment of contamination control objectives.

g. Inform other company employees and organizations of contamination control needs and activities, including the logic and reasoning for the requirements and restrictions imposed.

h. Train other company personnel to achieve the proficiency required to maintain contamination control standards.

i. Serve as a contamination control consultant to company organizations needing technical advice or assistance.

j. Keep abreast of the latest developments in the contamination control field.

k. Project future contamination control needs based on future product and activity planning.

10.6.3 Maximizing the Potential Cost Effectiveness of the Contamination Control Specialist

Anyone who has attained the status of a contamination control specialist represents a sizable investment in academic and professional training. Assuming that such an individual is needed and can be obtained, his services must be properly and fully utilized throughout the company with which he is associated.

If a contamination control specialist is relegated to the role of a technician, his value to the company will be seriously reduced. If, however, he is established in a peer position with the engineering and technical staff, he will be able to make a significant contribution to increased cost effectiveness. In the latter case, he can be an economically profitable asset rather than an expensive luxury.

Operating from a technically and organizationally favorable position, the contamination control specialist can provide maximum economic returns to his company in the following manner:

a. By reviewing proposed product designs, he should be able to deal effectively with potential contamination control problems and losses due to improper tolerances, configurations, and the use of materials.

b. He can determine appropriate product cleanliness levels and prescribe controls to achieve these levels at the optimum cost.

c. He can evaluate the effectiveness of various cleaning methods, equipment, and materials so that items purchased will be adequate but not excessive for the needs.

d. Many contamination control problems are the direct result of inadequately trained personnel and noncompliance with established practices. The contamination control specialist can lessen the effect of these conditions by developing training programs and monitoring the adherence to such practices.

Perhaps this brief philosophical discussion presents the ideal situation. Some companies, because of their organizational structure or personnel policies, may not be able to completely follow this concept. However, if a company has a need for a contamination control specialist, it can maximize the value of his services by placing him in the position from which he can function effectively.

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SECTION 11

GLOSSARY

ABSORPTION -- Penetration of a substance into the body of another; to take in and incorporate; assimilate.

ACID -- A substance whose molecules ionize in water solutions to give off hydrogen ions; a substance which registers less than 7 on the pH scale.

ACOUSTICS -- The science of sound, its production, transmission, and effects.

ADSORPTION -- Adhesion of the molecules of a gas, liquid, or dissolved substance to a surface; the taking up of one substance at the surface of another.

AEROBIC MICROORGANISMS (or obligate aerobic) -- Grow only in the presence of free or atmospheric oxygen.

AEROSOL -- A suspension of microscopic solid or liquid particles in air or gas.

AGGLOMERATION -- The combining, joining, clumping, or clustering of two or more particles or droplets by any means.

AIRBORNE -- Suspended or carried in a gas or airstream.

AIR-CLEANLINESS CLASS -- Each class of air cleanliness is determined by the particle count per unit volume, based on tabulation of particles 0.5 micron and larger or 5.0 microns and larger. Examples of standard air-cleanliness classes are described and illustrated in Paragraph 5.1, and Tables I and II in FED. STD. No. 209a.

AIRLOCK -- A chamber with doors functioning to maintain pressure during entry to and exit from an enclosed area.

AIR SHOWER -- A chamber with interlocked doors and equipped with an exhaust system, having numerous air nozzles arranged in a predetermined pattern, for the purpose of forcibly blowing loose particles, fibers, dust, and other particulate matter from the person and garments.

ALIPHATIC HYDROCARBON -- An organic compound having an open chain structure; as a class, petroleum-type solvents.

ALKALI -- Any base or hydroxide that is soluble in water and can neutralize acids; a substance that registers more than 7 on the pH scale.

AMBIENT CONDITION -- Environmental conditions such as pressure, temperature, humidity, etc., which are normal for one specific location.

ANAEROBIC MICROORGANISMS (or obligate anaerobic) -- Grow in an environment with no free oxygen.

ANTISEPTIC -- A substance that has sufficient antimicrobial activity to interfere with the development of infection but which is nontoxic to living tissue.

ASSEMBLY -- Two or more parts, subassemblies, or any combination thereof, joined together to perform a specific function.

AUTOTROPHIC MICROORGANISMS -- Capable of growth in the presence of only simple salts and carbon dioxide; the sole source of carbon is usually carbon dioxide.

BACTERICIDE -- A substance capable of killing bacteria.

BIOCLEAN FACILITY -- Any enclosed area (room or work station) characterized by having its own filtered air or gas supply where there is control over viable and nonviable particulates in air with temperature, humidity, and pressure control as required to maintain standards for the product.

BLOCKING -- The physical phenomenon of a material sticking or adhering to itself in the presence of heat; an undesirable characteristic for packaging films at temperatures under 200°F.

CAVITATION -- The formation of cavities, such as the microscopic vacuum pockets created in a solution by ultrasonic energy (or any mechanical energy).

CHEMOTROPH -- An organism whose primary energy source is chemical.

CLEANABLE -- Capable of being cleaned to specified levels without detrimental effect.

CLEAN-DOWN CAPABILITY -- The time required for a clean room to recover and return to its normal level or class of air cleanliness, after introduction or generation of any unusual quantity of contaminants.

CLEANING -- Act of removing unwanted substances.

CLEANING AGENT -- Any compound or substance which promotes the removal of soils through mechanical or chemical action.

CLEAN ITEM -- A part, component, or system which is wholly cleaned or has significant surfaces which have been cleaned and verified to a specified level of cleanliness.

CLEANLINESS LEVEL -- An established maximum allowable distribution of contamination of a given size and quantity in a stipulated area or volume.

CLEAN PACKAGING -- The application of clean preservation and packaging measures and material to maintain the cleanliness of a clean item during handling, storage, or shipment.

CLEAN ROOM -- A clean room is an enclosed area employing control over the particulate matter in air with temperature, humidity, and pressure control as required. To meet the requirements of a "clean room," the area must meet the particulate count as specified in FED. STD. 209a, Paragraph 5.1.3.

CLEAN WORK STATION -- A work bench or similar working enclosure characterized by having its own filtered air supply. The filters must be capable of providing the required air-cleanliness level.

CLONE OF CELLS -- The aggregate of asexually produced cellular progeny.

COLD BOIL -- Cavitation which is not dependent upon heat for its bubbling action.

CONIDIA -- The reproductive structure of certain fungi; an asexual spore.

CONTAINER -- Any receptacle or flexible covering capable of completely enveloping an item or items.

CONTAMINANT -- Any material, substance or energy which is unwanted or adversely affects the contaminee.

CONTAMINATE -- The act of introducing any contaminant; to make impure or unclean; to pollute, defile, sully, taint, or soil.

CONTAMINATION -- The presence of one or more contaminants in or on the contaminee.

CONTAMINATION CONTROL -- The planning, organization, and implementation of all activities needed to determine, achieve, and maintain a required cleanliness level in, on, or around the contaminee.

CONTAMINEE -- That which is or can be contaminated. Contaminees may be products, materials, devices, people, gases, or surfaces.

CONTROLLED AREA -- Any enclosure which has a degree of control of contaminants in air, gases, and fluids (may include temperature, humidity, and pressure) and which will not qualify as a clean room.

CROSS CONTAMINATION -- The migration of contaminants from one work location to another work location.

CURIE POINT -- The temperature at which the ultrasonic piezoelectric effect can no longer be produced.

CYCLE -- One beat of a vibrating body. One complete sound or electromagnetic wave.

CYTOPLASM -- The living matter of a cell between cell membrane and nucleus.

DECONTAMINATION -- The process of removing unwanted matter; the reduction of contamination to an acceptable level.

DEIONIZATION -- The removal of mineral ions from water.

DESIGN PACKAGING -- The enclosure of a unitized assembly of components, or parts in a protective container, covering or coating which is an integral part of the item and will enhance the function of the item; usually involves the use of sealed cans, encapsulating compounds, etc.

DIATOMACEOUS EARTH -- A light, friable, siliceous material derived chiefly from diatoms (minute planktonic algae); chiefly used for filters.

DIRECT TEST -- Any surface cleanliness test in which the parameter measured is the amount of soil remaining on a surface (see INDIRECT TEST).

DISINFECTANT -- An antimicrobial substance that destroys all (vegetative) microorganisms; applied to inanimate material; may be toxic.

DISTILLATION -- The phase changes from liquid to vapor to liquid; a process for removing impurities from liquids.

D-VALUE -- The time to kill 90 percent of a given population of microorganisms at a given temperature.

ELECTROSTATIC -- Pertaining to the phenomena due to attractions and repulsions of electrical charges.

ELECTROSTRICTION -- The use of an electric charge to change the dimensions in certain crystals; the principle used in some ultrasonic transducers.

EMISSION FACTOR -- A statistical average of the rate at which contaminants are emitted from any given source.

EMULSION -- A liquid in which other particles or liquids are suspended; a characteristic of some cleaning agents in holding and carrying away soils.

ENTRAPMENT -- The act of securing and holding, as dirt is entrapped in a filter.

ENVIRONMENT -- The total of all factors which might influence or cause contamination of a contaminee. The primary factors of environment are the forms air, gas, liquid, solid, or surfaces.

ENVIRONMENTALLY ADJACENT -- A condition in which packaging materials are not in direct contact with clean or significant surfaces but are exposed to these surfaces.

ENVIRONMENTAL PACKAGE -- A clean material closure, wrap or container over the intimate package that is sealed to provide an additional contamination barrier to protect the intimate package and its contents from environmental elements.

FACE VELOCITY -- A measure of lineal airflow at approximately 12 inches from the down-stream face of a filter.

FACULTATIVE -- Ability to live or thrive under more than one set of conditions, i.e., a microorganism that can live in the presence or absence of oxygen.

FILTER -- A device using a medium to selectively separate certain substances from a given environment.

FILTRATION -- The process of removing contaminants from a gas or liquid by passing them through a porous media.

FIRST-ORDER REACTION -- To be first order, the rate of a chemical reaction must be proportional to the concentration of one reactant. If the rate is proportional to the product of two concentrations or the square of one concentration, the reaction is second order.

FIXTURE -- A device for holding a work piece in a fixed position while fabrication and assembly processes are performed.

FREE RADICAL -- A chemical species that has an unpaired electron; species having an odd number of electrons.

FREQUENCY -- The number of vibrations, or cycles per second.

FUNGI -- Microorganisms which lack chlorophyll and generally possess filamentous vegetative structures, i.e., yeasts, molds, rusts, mildews, smuts, etc.

GAS -- A state of matter in which the molecules are practically unrestricted by cohesive forces. A gas has neither shape nor volume, and in form is neither liquid nor solid.

GAS CYLINDER SAFETY RELIEF DEVICE -- A device installed in a gas cylinder or container to prevent rupture of a cylinder by overpressures as a result of certain conditions of exposure. Such a device includes a frangible disc, fusible plug, or relief valve.

GAS PRESSURE REGULATOR -- A device that may be connected to the cylinder valve outlet to regulate the gas pressure delivered to a system.

GENUS -- A group marked by common characteristics or by one common characteristic; a category of biological classification between the family and the species.

GERM -- A microorganism, usually a bacterium, which can produce disease.

GERMICIDE -- A substance capable of killing germs.

GOX -- Gaseous oxygen.

HERTZ (Hz) -- One cycle per second.

HETEROTROPH -- Microorganisms that require preformed organic compounds for their carbon source.

HIGH EFFICIENCY PARTICULATE AIR FILTER (HEPA) -- MIL-F-51068A specifies filters with minimum efficiency of 99.97 percent determined by the homogeneous DOP method at airflows of 20 and 100 percent of the rated flow capacity of the filter. It is referred to as the HEPA filter.

HORIZONTAL LAMINAR AIRFLOW CLEAN ROOM -- A room equipped with one entire vertical wall of HEPA filters, through which the air passes at a predetermined speed to an exhaust wall directly opposite the HEPA filter wall. The entire body of air moves horizontally across the room along essentially parallel flow lines at uniform velocity.

HYDROCARBON -- A chemically identifiable compound of carbon and hydrogen.

HYDROPHILIC SOIL -- Soil which exhibits an affinity for water or is miscible with water.

HYDROPHOBIC SOIL -- Soil which exhibits a lack of affinity for or miscibility with water; nonwetting.

HYPHAE -- The "threads" that make up the mycelium (filamentous structures) of a fungus.

IMPLOSION -- A bursting inward; the opposite of an explosion. When the cavitations in an energized solution collapse, implosion occurs.

INDIRECT TEST -- Any surface cleanliness test in which the parameter measured is the amount of soil removed from a surface (see DIRECT TEST).

INTERMEDIATE PACKAGING -- The application or use of a closure, wrap, covering or container over the clean package to provide general physical protection to preserve the integrity of the clean package.

INTIMATE CUSHIONING -- A clean material used to protect additional packaging materials from puncture or damage caused by the clean item.

INTIMATE PACKAGE -- A clean material closure, wrap or container that will have intimate contact with, or is environmentally adjacent to, the clean item or surface, and is sealed to provide a barrier to external contaminants and environments.

IODOPHORE -- Organic compounds of iodine in which iodine is loosely combined with some surface active agent; nonstaining, nonirritating, and practically odorless.

KAURI-BUTANOL VALUE -- A numeric designation indicating the solvency power of a cleaning agent. The kauri-butanol value for benzene is 100.

KILOCYCLE (kc) -- 1000 cycles.

KILOHERTZ (kHz) -- 1000 Hertz or 1000 cycles per second.

LAMINAR AIRFLOW -- Airflow in which the entire body of air within a confined area moves with uniform velocity along parallel flow lines.

LAMINAR AIRFLOW CLEAN WORK STATION -- A work station in which the laminar airflow characteristics predominate throughout the entire air space.

LAMINAR AIRFLOW ROOM -- A room in which the laminar airflow characteristics predominate throughout the entire air space.

LATENT HEAT -- The calories of heat required to change one gram of liquid to vapor at the boiling point.

LETHAL -- An agent capable of causing death.

LIQUID -- A state of matter in which the molecules are relatively free to change their positions with respect to each other but restricted by cohesive forces so as to maintain a relatively fixed volume.

LOX -- Liquid oxygen.

MAGNETOSTRICTION -- Applying an alternating magnetic field in the direction of a metal rod's axis to change its length. This is the principle used in the lower cycle (20 to 25 kc) ultrasonic transducers.

MECHANISM -- The physical or chemical means or process by which a natural action, reaction or result is achieved.

MEMBRANE FILTER -- Cellulose plastic porous membrane material with controlled pore sizes ranging from 5 microns downward to approximately 8 millimicrons, composed of 15 to 20 percent solid material and 80 to 85 percent void.

METABOLISM -- The total chemical changes by which the nutritional and functional activities of an organism are maintained. (Subdivisions: Anabolism - synthesis; Catabolism - degradation.)

MICROBE -- An organism of microscopic or submicroscopic size, generally including viruses, rickettsiae, bacteria, algae, yeasts, and molds.

MICRON -- A unit of measurement equal to one-millionth of a meter or approximately 0.00003937 inch (e.g., 25 microns are approximately 0.001 inch).

MIGRATION -- Act of changing locations; moving from place to place, as fine dust is moved by air currents or agitation.

MOLECULAR ATTRACTION -- The adhesive forces exerted between the surface molecules of two bodies in contact.

MONITOR -- To systematically check or test for the purpose of controlling the concentration of a specific ingredient or the execution of a process. May include qualitative or quantitative measurements, or both.

MUTAGENIC -- A substance capable of inducing mutations, i.e., a stable change of a gene.

MYCELIUM -- A mass of threadlike structures constituting the vegetative structure of a fungus.

NONLAMINAR FLOW CLEAN ROOM -- A room characterized by nonuniform airflow patterns and velocities.

NONLAMINAR FLOW CLEAN WORK STATION -- A work station characterized by nonuniform air patterns and velocities.

NUCLEUS -- The portion of the cell protoplasm essential to the cell's vital phenomena and perpetuation.

NYLON -- A polyamide with high abrasion resistance, but relatively poor moisture barrier characteristics.

ORGANIC -- Designating any chemical compound containing carbon.

OXIDE -- A binary compound of oxygen with some other element or with a radical.

PACKAGING -- The application or use of appropriate closures, wrappings, cushioning, containers, and complete identification, up to, but not including the shipping container and associated packing.

PACKAGING FILM -- Any film or sheet material used as a packaging wrap or container; usually limited to thicknesses less than 10 mils.

PACKING -- The application or use of exterior shipping containers with the packages therein, together with necessary blocking, bracing, cushioning, weather proofing, and exterior strapping of the shipping container to protect and preserve the integrity of the packaged item during shipment or extended storage.

PARTICLE -- A piece of matter with observable length, width, and thickness; usually measured in microns.

PARTICULATE MATTER -- The general term applied to matter of miniature size, with observable length, width, and thickness, and contrasted to nonparticulate matter without definite dimension.

pH -- Potential of Hydrogen; a symbol for the logarithm of the reciprocal of the hydrogen ion concentrations, expressed in gram atoms per liter of a solution; used to indicate acidity or alkalinity.

PHOTOTROPH -- An organism whose primary energy source is light.

PIEZOELECTRICITY -- Same as ELECTROSTRICTION.

PLENUM -- An enclosed space in which the air pressure is greater than that of the adjoining outside area.

POLLUTE -- See CONTAMINATE.

POLYETHYLENE -- A thermoplastic polymer capable of being produced in thin sheets; exhibits good moisture-vapor barrier qualities but has a high sloughing tendency.

PRECLEANING -- That cleaning which is accomplished outside of a clean area, for the purpose of removing contaminants such as rust, oxidation, grease, oil, heavy scale or soil deposits to control the amount of contaminants brought into the clean room.

PRESSURE DROP -- The pressure differential resulting from forcing a gas or liquid through a restricting media.

QUANTUM -- A theoretical increment or parcel into which many forms of energy are subdivided.

RADIATION -- The process of emitting radiant energy in the form of waves or particles.

REAGENT -- A substance used to produce a characteristic reaction in chemical analysis.

SELF CLEAN-DOWN -- The ability of a clean room or work station to purge itself of contaminants generated within its area.

SHEDDING -- See SLOUGH.

SIGNIFICANT SURFACE -- The surface of a part, component, or system which contacts the operating medium of a system and requires a specified level of cleanliness which must be maintained for proper operation.

SLOUGH -- To release particles of the base material as a result of erosion or abrasion.

SOIL -- See CONTAMINANT.

SOLID -- A state of matter in which the relative motion of molecules is restricted; the molecules tend to retain a fixed position relative to each other.

SOLVENT -- That solution or constituent of a solution which exhibits the capability to dissolve other substances through chemical action.

SONOCHEMISTRY -- Acceleration of chemical effects by the use of ultrasonics.

SPECIES -- One kind of organism; the subdivision of a genus.

SPECIFICATION -- A document which establishes specific and individual requirements for processes, product, and product performance.

SPECIFIC HEAT -- The thermal capacity of a liquid as a ratio of that of water at 15°C.

STANDARD -- A uniform method of defining basic parameters for processes, product, or measurements.

SURFACE TENSION -- A phenomenon of molecular attraction between the molecules of a liquid which tends to contract the exposed surface to the smallest possible area; expressed as dynes per centimeter.

TLV -- Threshold Limit Value; a guideline between safe and probably dangerous concentrations having adverse effects on personnel; as recommended by the American Conference of Governmental Industrial Hygienists.

TOXIC -- Poisonous.

TRANSDUCER -- A device that converts energy from one form to another. An ultrasonic transducer changes high-frequency electrical energy into high-frequency sound waves.

UBIQUITOUS -- Present everywhere or in many places.

ULTRASONICS -- The physical science of those acoustic waves that oscillate in the approximate range of 18 to 80 kHz.

VAPOR -- The gaseous form of any substance which is usually a liquid or a solid.

VERTICAL LAMINAR AIRFLOW ROOM -- A room equipped with a ceiling of HEPA filters, with a grated or perforated floor for the exhausting of air issuing from the ceiling filters; the airflow is vertical, and moves within the walled area along essentially parallel lines at uniform velocity.

VIABLE -- Capable of living; growing, or developing; metabolizing.

WAVELENGTH -- The distance between two undulations of a wave train.

SECTION 12

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